Pleasant and Riddles Lakes Watershed Diagnostic Study

St. Joseph County, Indiana

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PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY
ST. JOSEPH COUNTY, INDIANA

EXECUTIVE SUMMARY

Pleasant and Riddles Lakes are 29-acre and 77-acre (11.7-ha and 31.2-ha) lakes, respectively that lie south of Lakeville in St. Joseph County, Indiana. The lakes lie in the headwaters of the Yellow River Basin which carries water south and west to the Kankakee River. The Pleasant and Riddles Lakes watershed encompasses approximately 7,730 acres (3,129 ha). Most of the watershed (68%) is utilized for agricultural purposes (row crops, hay, and pasture). Remnants of the native landscape, including forested areas and wetlands, cover approximately 20% of the watershed, while residential and commercial land uses account approximately 10% of the watershed's total acreage. Pleasant and Riddles lakes cover an additional 2% of the total watershed.

Pleasant Lake has two primary tributaries, Heston and Bunch ditches. Heston Ditch during base flow and Bunch Ditch during storm flow delivered the highest load of pollutants to the watershed lakes. Both streams possessed poor biotic communities, with the macroinvertebrate community integrity scores reflecting the ditches poor water quality. Heston and Bunch ditches' biotic communities fell in the "moderately impaired" category using the Indiana Department of Environmental Management's scoring criteria. Of greatest concern in Bunch Ditch were the stream's low dissolved oxygen and elevated *E. coli*, total phosphorus, and total Kjeldahl nitrogen concentrations, which were all outside the recommended criteria or applicable state standards during the base flow monitoring event.

Riddles Lake has two primary tributaries, Heston and Walters ditches. Walters Ditch exhibited poor water quality during base flow, or "normal", conditions and high *E. coli*, total phosphorus, and total suspended solids concentrations during storm flow conditions. The stream's biotic community integrity score reflected its moderate water quality; Walters Ditch's biotic community fell in the "slightly impaired" category using the Indiana Department of Environmental Management's scoring criteria. Of greatest concern were the stream's low dissolved oxygen and elevated *E. coli*, total phosphorus, and nitrate-nitrogen concentrations, which were all outside the recommended criteria or applicable state standard during both base and storm flow monitoring events.

Pleasant and Riddles lakes themselves are productive. Historical data for the lakes suggest that water quality has changed little within the lakes over the past 25 years. During the current assessment, the lakes possessed poorer water clarity and higher nutrient levels than most Indiana lakes. Evaluating the lakes using various trophic state indices suggest the lakes are eutrophic to hypereutrophic in nature. The lakes also support a limited submerged plant community that includes two exotic species, Eurasian water milfoil and curly-leaf pondweed. Also of concern is the predominance of gizzard shad in the lakes. However, the lakes continue to offer good fishing opportunities.

Improving water quality in Pleasant and Riddles lakes will require both in-lake and watershed management. The lakes possess extremely short hydraulic residence times measuring 0.08 years (29.2 days) for Pleasant Lake and 0.11 years (40 days) for Riddles Lake. The results of the inlet sampling and the phosphorus modeling indicate the watershed is capable of contributing significant amounts of nutrient and sediment to the lake, making good watershed management a necessity. The lakes' relatively large watershed area to lake area ratio of 192:1 for Pleasant Lake and 99:1 for Riddles Lake suggests near watershed practices have substantial control over influencing the health of these lakes.

Recommended watershed management techniques include: wastewater treatment plant maintenance, erosion control practices for existing and future developments, homeowner best management practices, wetland restoration, use of the Conservation Reserve Program and conservation tillage, and livestock restriction. Area stakeholders are encouraged to develop a comprehensive lake management plan for the lakes. This plan should include a rooted plant management section to protect the plant community's health.

ACKNOWLEDGEMENTS

The Pleasant and Riddles Lakes Watershed Diagnostic Study was made possible with funding from the Indiana Department of Natural Resources (IDNR) Division of Fish and Wildlife and the Lakeville Business Owners Association. The Pleasant and Riddles Lakes Watershed Diagnostic Study was completed by JFNew and their subcontractor, Indiana University School of Public and Environmental Affairs. Contributors to this study included Cecil Rich and Bob Robertson with the IDNR Division of Fish and Wildlife and Ron Hellmich with the IDNR Division of Nature Preserves. Special thanks to the dedicated members of the Lakeville Business Owners Association for their initiative and assistance in getting this study completed. Area residents who participated in the study included: Bob Feitz, who served as the primary liaison between JFNew and the Lakeville Business Owners Association, kept an eagle eye on the precipitation, or lack there of, and helped collect and deliver samples to the laboratory; Rex Edward, who navigated JFNew biologists around the lake during the rooted plant survey; and Donald Kiiskila for his insight during the watershed tour. Authors of this report included William Jones, Chris Bobay, Sheela Doshi, Melissa Clark, Aaron Johnson, David Fuente, and Rachel Price at Indiana University and Sara Peel, John Richardson, Joe Exl, Mark Pranckus, and Scott Namestnik at JFNew.

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PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY
ST. JOSEPH COUNTY, INDIANA

1.0 INTRODUCTION

Pleasant and Riddles Lakes are 29-acre and 77-acre (11.7-ha and 31.2-ha) lakes, respectively that lie in the south central portion of St. Joseph County, Indiana (Figure 1). Specifically, Pleasant Lake is located in Michigan Range Land 1 (MRL 1) and Riddles Lake in Sections 2 and 11 of Township 35 North, Range 2 East in St. Joseph County. The Pleasant and Riddles lakes watershed stretches out to the north and west of the lakes encompassing 7,731 acres (3,129 ha; Figure 2). Water flows from Pleasant Lake to Riddles Lake before discharging out of Riddles Lake's outlet in the southeast corner of the lake to Stock Ditch. Water from Stock Ditch combines with drainage from the East Fork Bunch Ditch and the West Fork Bunch Ditch before flowing into the Yellow River southwest of Bremen. The Yellow River transports water south and west to the Kankakee River which eventually discharges water to the Illinois River in northeast Illinois. Pleasant and Riddles lakes watershed runoff eventually reaches the Mississippi River in southern Illinois.

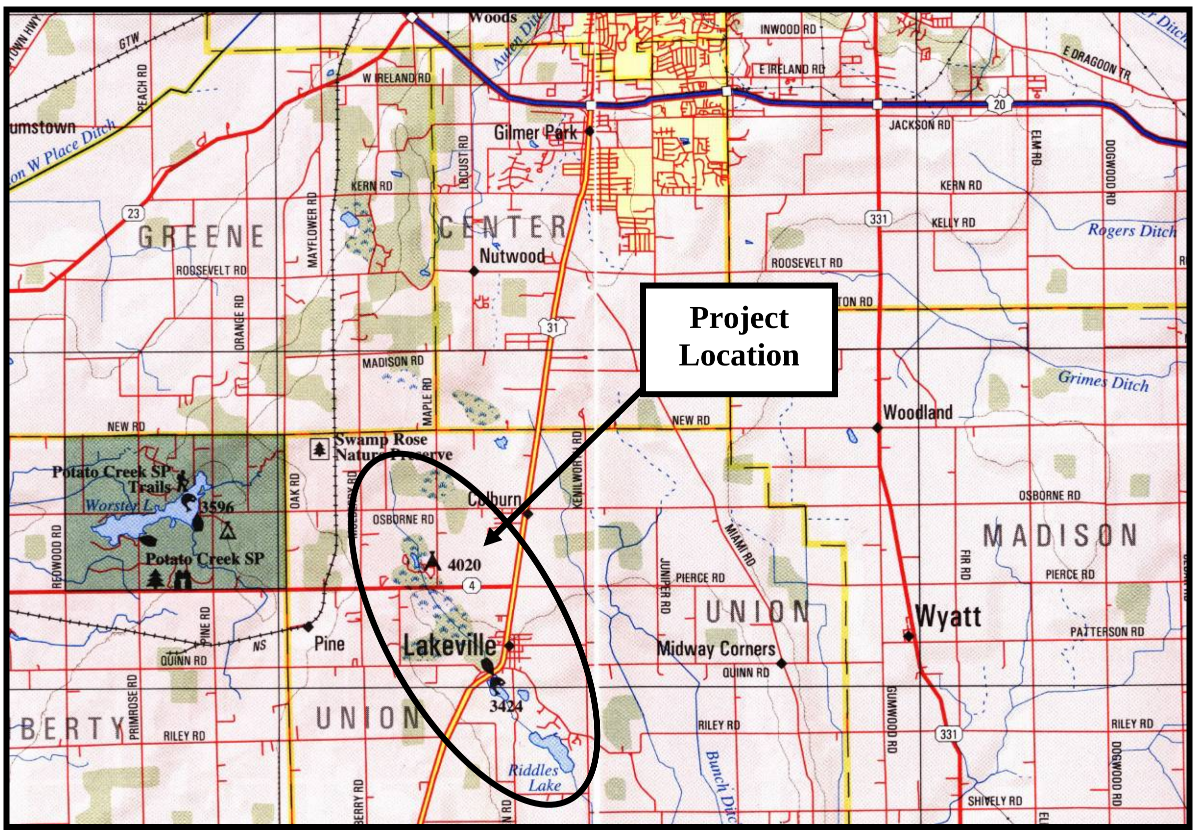

Figure 1. General location of the Pleasant and Riddles lakes watershed. Source: DeLorme, 1998.

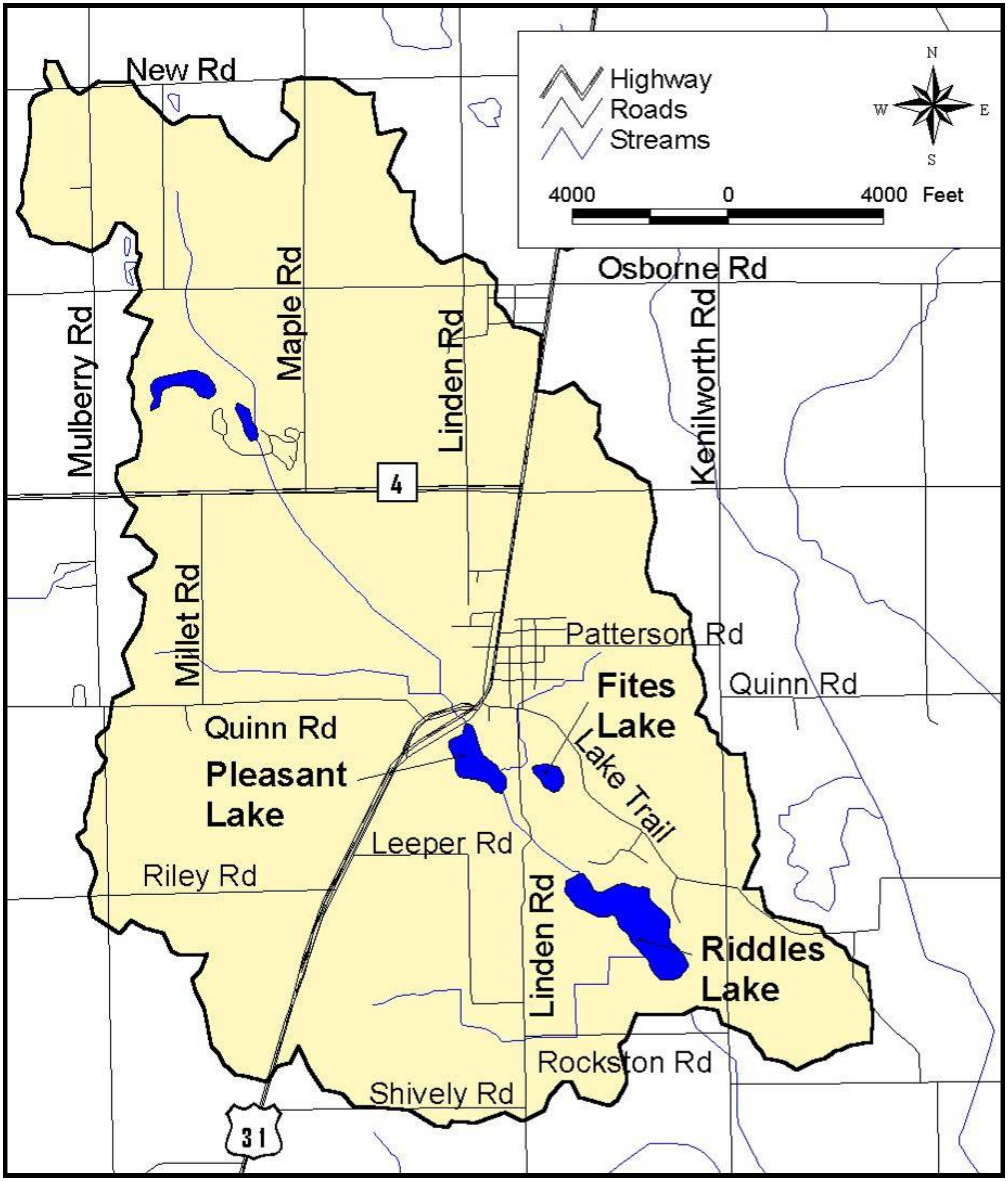

Figure 2. Pleasant and Riddles lakes watershed. Source: See Appendix A. Scale: 1"=4,000'.

Pleasant and Riddles lakes have historically exhibited moderately poor water quality characteristic of highly productive (eutrophic) lakes. The lakes' water clarity has fluctuated over the past 30 to 40 years but has ultimately changed little over time. Both Pleasant and Riddles lakes possess relatively poor clarity when compared to other lakes in the region. Historical records indicated that both lakes possess Secchi disk transparencies (a measure of water clarity) poorer than 3 feet (0.9 m). These data indicate that current water quality in both lakes is poorer than the regional median of less than 6 feet (1.8 m) (Giolitto, 2002). Current transparencies measure 2.3 feet (0.7 m) in both lakes. Pleasant and Riddles lakes also possess extremely high total phosphorus concentrations measuring 0.408 mg/L and 0.554 mg/L throughout the water column, respectively. Total phosphorus concentrations are elevated compared to the statewide and regional median values (Clean Lakes Program data files, unpublished; Giolitto, 2002; CLP data files, 2005). Primary productivity of the lake (algae and plant growth) has been relatively high as well. Chlorophyll *a* concentrations (an indicator of algae production) were greater than 148 μg/L in 2004 and 37 μg/L in 2005 in Pleasant Lake, likewise, chlorophyll *a* concentrations were greater than 101 μg/L in 1999 and 44 μg/L in 2005 in Riddles Lake. Concentrations this high are typical of hypereutrophic lakes.

Poor water clarity, low dissolved oxygen levels, and elevated nutrient concentrations coupled with the presence of a high percentage of gizzard shad within both Pleasant and Riddles lakes contributes to the moderate fishing quality of the lakes. Bluegill and gizzard shad have been co-dominant members of the Pleasant Lake fishery since IDNR surveys began at the lake in 1972. Largemouth bass are a minor component of the Pleasant Lake fishery. Despite the pressure from gizzard shad competition, the Pleasant Lake fishery maintains its good quality. However, the predominance of gizzard shad in Riddles Lake coupled with elevated nutrient concentrations and poor water clarity indicates that Riddles Lakes fishery may be declining. Continued management of the fishery through the introduction of largemouth bass and control of gizzard shad populations should improve the fishery quality and assist the Conservation Club in maintaining a high quality fishery.

The composition and structure of Pleasant and Riddles lakes' rooted plant communities indicate that water quality within the lakes is equitable with what the water chemistry data indicate. Both lakes are dominated by a mix of emergent, floating, and submerged species including Eurasian watermilfoil, coontail, curly-leaf pondweed, spatterdock, filamentous algae, watermeal, duckweed, and purple loosestrife. These species are common in lakes with poor water clarity and elevated nutrient concentrations. In fact, many of these species consume nutrients directly from the water column. In total, 40 aquatic plant species cover nearly 37% of Riddles Lake's surface area, while 26 species cover nearly 60% of Pleasant Lake's surface area.

Lakeville and shoreline residents and Lakeville Conservation Club members have been proactive in protecting their lakes' health. Residents have worked on their own and with natural resource agencies to try to treat problems in the lake and its watershed. Lakeville installed a sewer system and treatment plant, eliminating septic systems in the town and other drainage that use to be directed toward the lakes to help improve the water quality. Residents in the Walters Ditch subwatershed have also implemented water quality improvement projects suggested by IDNR Resource Specialists. Other individual watershed property owners have placed land in Conservation Reserve Program set-asides and installed grassed waterways to reduce sediment transport from the watershed to Pleasant and Riddles lakes. While these practices have slowed the import of sediment to Pleasant and Riddles lakes from their watershed and the conversations have sparked the interest of watershed residents, members of the Lakeville Business Owners Association (LaBOA) have identified additional areas of concerns. Lake residents have also expressed a desire to learn about practices the can be implemented on residential properties that might improve the lake's water quality. To achieve these goals, the LaBOA applied for and received funding from the IDNR Lake and River Enhancement Program (LARE) to complete a diagnostic study of the lake.

The purpose of the diagnostic study was to describe the conditions and trends in Pleasant and Riddles lakes and their watershed, identify potential problems, and make prioritized recommendations addressing these problems. The study consisted of a review of historical studies, interviews with lake residents and state/local regulatory agencies, the collection of current water quality data, pollutant modeling, and field investigations. In order to obtain a broad understanding of the water quality in Pleasant and Riddles lakes and the water entering the lakes, the diagnostic study included an examination of the lake and inlet stream water chemistry and their biotic communities (macroinvertebrates, plankton, macrophytes) which tend to reflect the long-term trends in water quality. Additionally, Fites Lake, an undeveloped lake located in the watershed, was also sampled to provide a comparison of water quality. The lakes and inlet streams' habitat were also assessed to help distinguish between water quality and habitat effects on the existing biotic communities. This report documents the results of the study.

2.0 WATERSHED CHARACTERISTICS

2.1 Topography and Physical Setting

Pleasant and Riddles Lakes are headwaters lakes in the Mississippi River Basin. The lakes and their 7,731-acre (3,128-ha) watershed lie south of the north-south continental divide. Similar to its more famous cousin, the east-west Continental Divide which divides the United States into two watersheds, one that drains to the Atlantic Ocean and one that drains to the Pacific Ocean, the north-south continental divide separates the Mississippi River Basin (land that drains south to the Mississippi River) from the Great Lakes Basin (land that drains north to the Great Lakes). As part of the Mississippi River Basin, water from Pleasant and Riddles Lakes flows south out of St. Joseph County into the Yellow River. The Yellow River flows into the Kankakee River which eventually discharges into the Illinois River near Kankakee, Illinois. The Illinois River converges with the Mississippi River in southern Illinois.

The topography of the Pleasant and Riddles Lakes watershed reflects the geological history of the watershed. The highest areas of the watershed lie along the watershed's southern and western edges, where the Saginaw Lobe of the last glacial age left end moraines. Along the watershed's western boundary, the elevation nears 900 feet (274.3 m) above mean sea level. The ridge along the watershed's southwestern boundary is equally as high, but is much steeper than the ridge along the western watershed boundary. The highest point in the watershed corresponds with other recorded high elevations including St. Joseph County's highest point (900 feet or 274.3 m above sea level) which is located within Bendix Woods (Historical Preservation Society, 2000). Heston Ditch and its floodplain, including Fites Lake, occupy a lower elevation valley in the watershed. Pleasant and Riddles Lakes, elevation 818 feet (249.3 m) above mean sea level, are the lowest points in the watershed. Figure 3 presents a topographical relief map of the Pleasant and Riddles Lakes watershed.

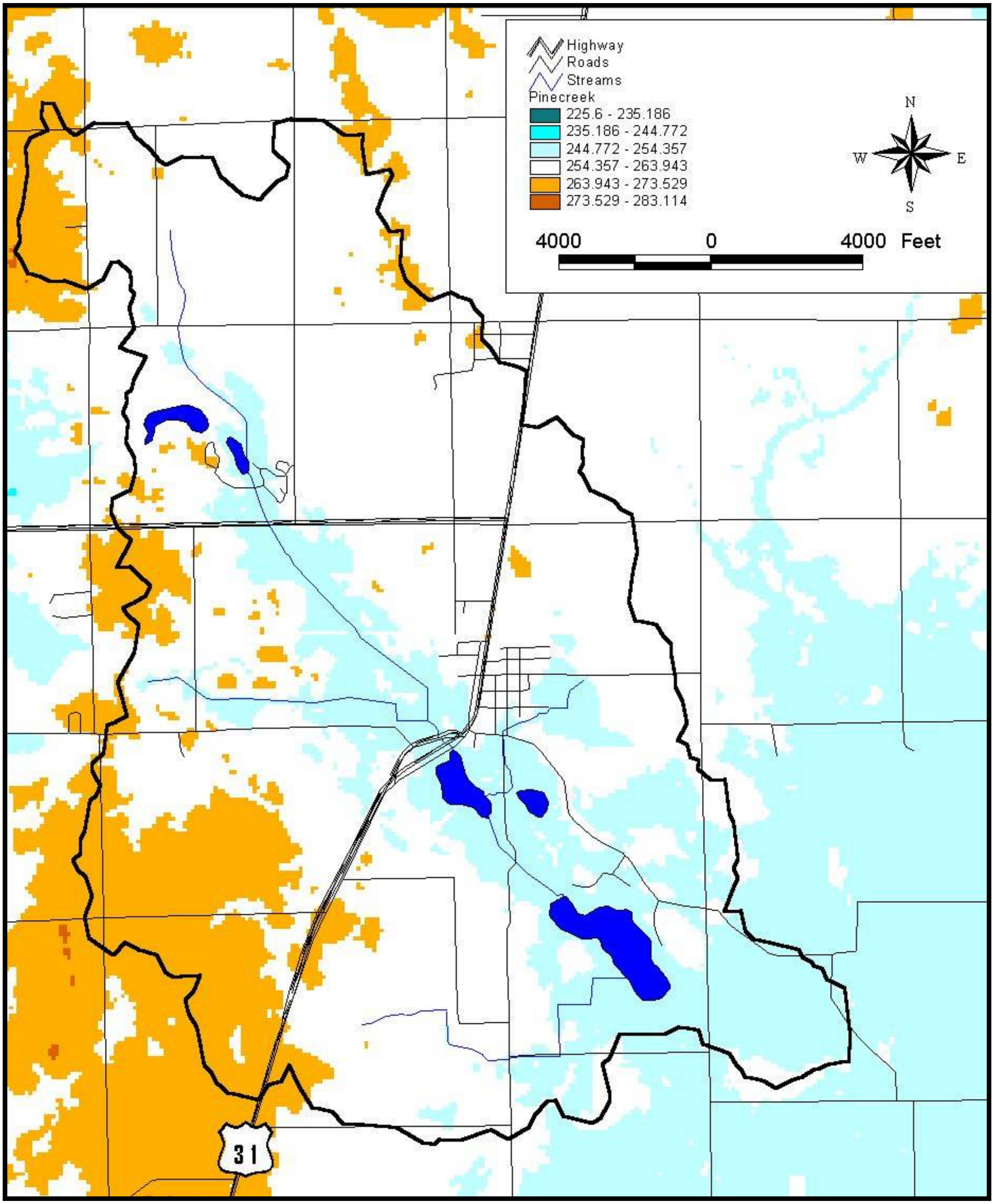

Figure 3. Topographical map of the Pleasant and Riddles Lakes watershed.
Source: See Appendix A. Scale: 1"=4,000'.

2.1.1 Riddles Lake

Surface water drains to Riddles Lake via three primary routes. Heston Ditch drains approximately 5,987 acres (2,223 ha) northwest of Riddles Lake (Table 1). This stream empties into Riddles Lake in the lake's northwest corner after trailing through Pleasant Lake. Walters Ditch transports water from the southwestern portion of the watershed to Riddles Lake along Rockstroh Road. This stream drains approximately 977 acres (395 ha or 13%) of the Riddles Lake watershed. The remainder of the land in the Riddles Lake watershed (767 acres or 310 ha) drains directly to Riddles Lake. Figure 4 illustrates the boundaries of each of the three subwatersheds of Riddles Lake.

Table 1. Watershed and subwatershed sizes for the Riddles Lake watershed.

Subwatershed/Lake	Area (acres)	Area (hectares)	Percent of Watershed
Heston Ditch	5,986.8	2,422.8	77.5%
Walters Ditch	977.6	395.6	12.6%
Area Draining Directly to Riddles Lake	689.8	279.3	8.9%
Watershed Draining to Lake	**7,654.2**	**3,097.5**	**99%**
Riddles Lake	77	31.2	1%
Total Watershed	**7,731.2**	**3,128.7**	**100%**
Watershed to Lake Area Ratio	99:1		

Table 1 also provides the watershed area to lake area ratio for Riddles Lake. Watershed size and watershed to lake area ratios can affect the chemical and biological characteristics of a lake. For example, lakes with large watersheds have the potential to receive greater quantities of pollutants (sediments, nutrients, pesticides, etc.) from runoff than lakes with smaller watersheds. For lakes with large watershed to lake ratios, watershed activities can potentially exert a greater influence on the health of the lake than lakes possessing small watershed to lake ratios. Conversely, for lakes with small watershed to lake ratios, shoreline activities and internal lake processes may have a greater influence on the lake's health than lakes with large watershed to lake ratios.

Riddles Lake possesses a watershed area to lake area ratio of approximately 99:1. This is a fairly large watershed area to lake area ratio for glacial lakes (Vant, 1987). This ratio is also relatively large compared to other lakes in the area. For example, Lake of the Woods, which has a similarly sized watershed, possesses a watershed area to lake area ratio of approximately 15:1. Likewise, Lawrence Lake, which is similar in size to Riddles Lake, has a watershed area to lake area ratio of approximately 5:1. Conversely, Lake Tippecanoe, Ridinger Lake, and Smalley Lake, glacial lakes in the Upper Tippecanoe River watershed in Kosciusko, Noble, and Whitley Counties, possess watershed area to lake area ratios of 93:1, 165:1, and 248:1, respectively. All of these lakes have extensive watersheds compared to Riddles Lake. Riddles Lake's watershed area to lake area ratio is well above the typical ratio for glacial lakes. Many glacial lakes have watershed area to lake area ratios of less than 50:1 and watershed area to lake area ratios on the order of 10:1 are fairly common. Riddles Lake's watershed area to lake area ratio is more typical of reservoirs, where the watershed area to reservoir area ratio typically ranges from 100:1 to 300:1 (Vant, 1987).

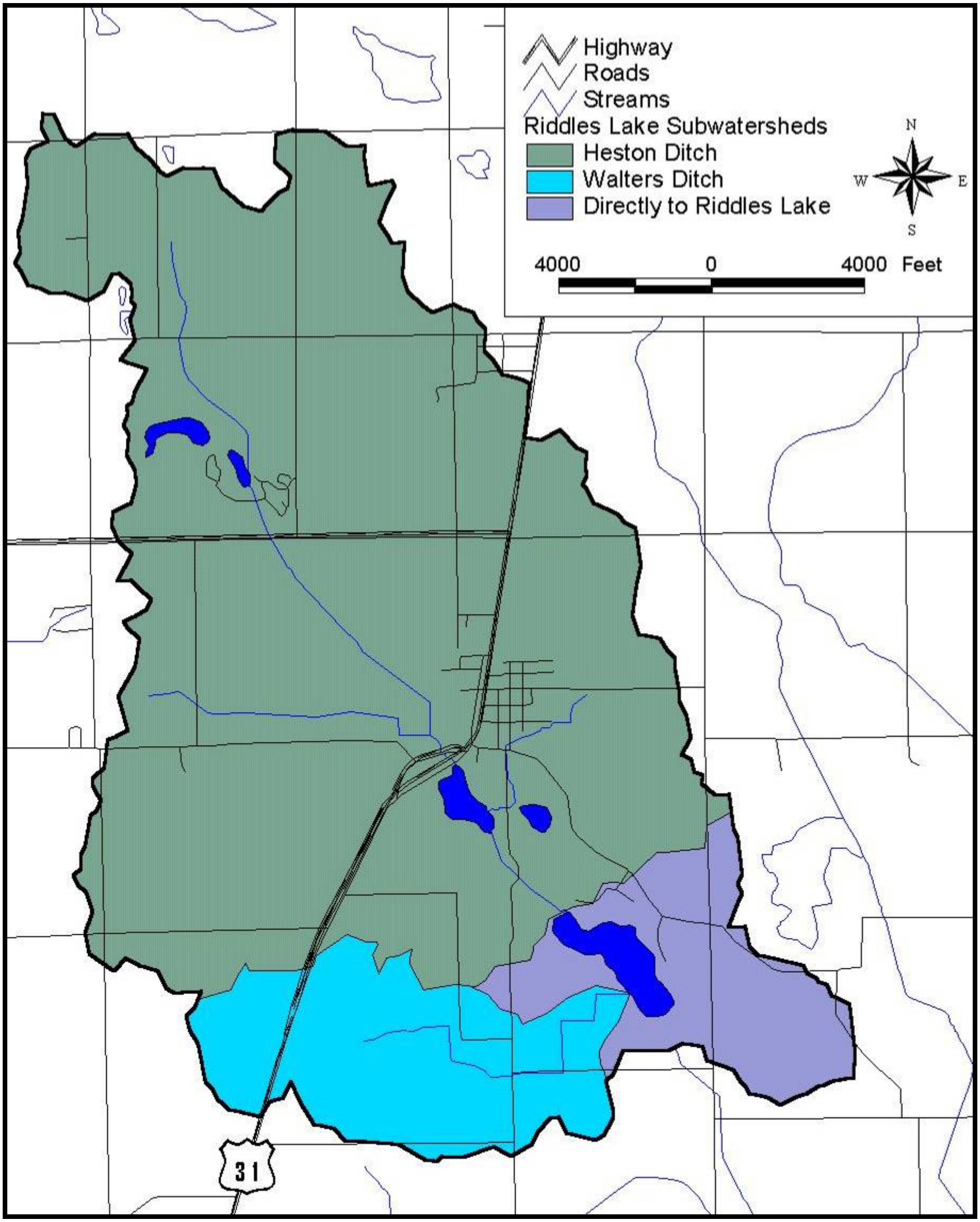

Figure 4. Riddles Lake subwatersheds.
Source: See Appendix A. Scale: 1"=4,000'.

In terms of lake management, Riddles Lake's large watershed area to lake area ratio means that watershed and near lake (i.e. shoreline) activities and processes can potentially exert a significant influence on the health of Riddles Lake. Consequently, implementing best management practices within the lake's watershed should rank high when prioritizing management options. Similarly, near shore management practices, such as maintaining native, emergent vegetated buffers between the lakeside residences and the lake, should receive special attention. This does not mean that in-lake management should be ignored. However, the relatively large watershed area to lake area ratio should be considered when prioritizing the use of limited funds for lake management.

2.1.2 Pleasant Lake

Surface water drains to Pleasant Lake via three primary routes. Heston Ditch drains approximately 4,305 acres (1,742 ha) north and west of Pleasant Lake (Table 2). This stream empties into Pleasant Lake along the lake's northern shoreline. Bunch Ditch transports water from the eastern portion of the watershed including drainage from a majority of Lakeville and Fites Lake to Pleasant Lake. This stream drains approximately 1,161 acres (470 ha or 21%) of the Pleasant Lake watershed. The remainder of the land in the Pleasant Lake watershed (137 acres or 55.6 ha) drains directly to Pleasant Lake. Figure 5 illustrates the boundaries of each of the three subwatersheds of Pleasant Lake.

Table 2. Watershed and subwatershed sizes for the Pleasant Lake watershed.

Subwatershed/Lake	Area (acres)	Area (hectares)	Percent of Watershed
Heston Ditch	4,305.5	1742.4	76.8%
Bunch Ditch	1,160.7	469.7	20.7%
Directly to Pleasant Lake	108.4	43.9	1.9%
Watershed Draining to Lake	**5,574.7**	**2,256.0**	**99.4%**
Pleasant Lake	29	11.7	0.6%
Total Watershed	**5,603.7**	**2,268.7**	**100%**
Watershed to Lake Area Ratio	192:1		

Like Riddles Lake, Pleasant Lake possesses a relatively large watershed area to lake area ratio (192:1). This is a fairly large watershed area to lake area ratio for glacial lakes. Pleasant Lake's watershed area to lake area ratio is more typical of reservoirs, where the watershed area to reservoir area ratio typically ranges from 100:1 to 300:1 (Vant, 1987). In terms of lake management, Pleasant Lake's large watershed area to lake area ratio means that watershed activities and processes can potentially exert a significant influence on the health of Pleasant Lake. Consequently, implementing best management practices within the lake's watershed should rank high when prioritizing management options. This does not mean that in-lake or near-shore management should be ignored. However, the relatively large watershed area to lake area ratio should be considered when prioritized the use of limited funds for lake management.

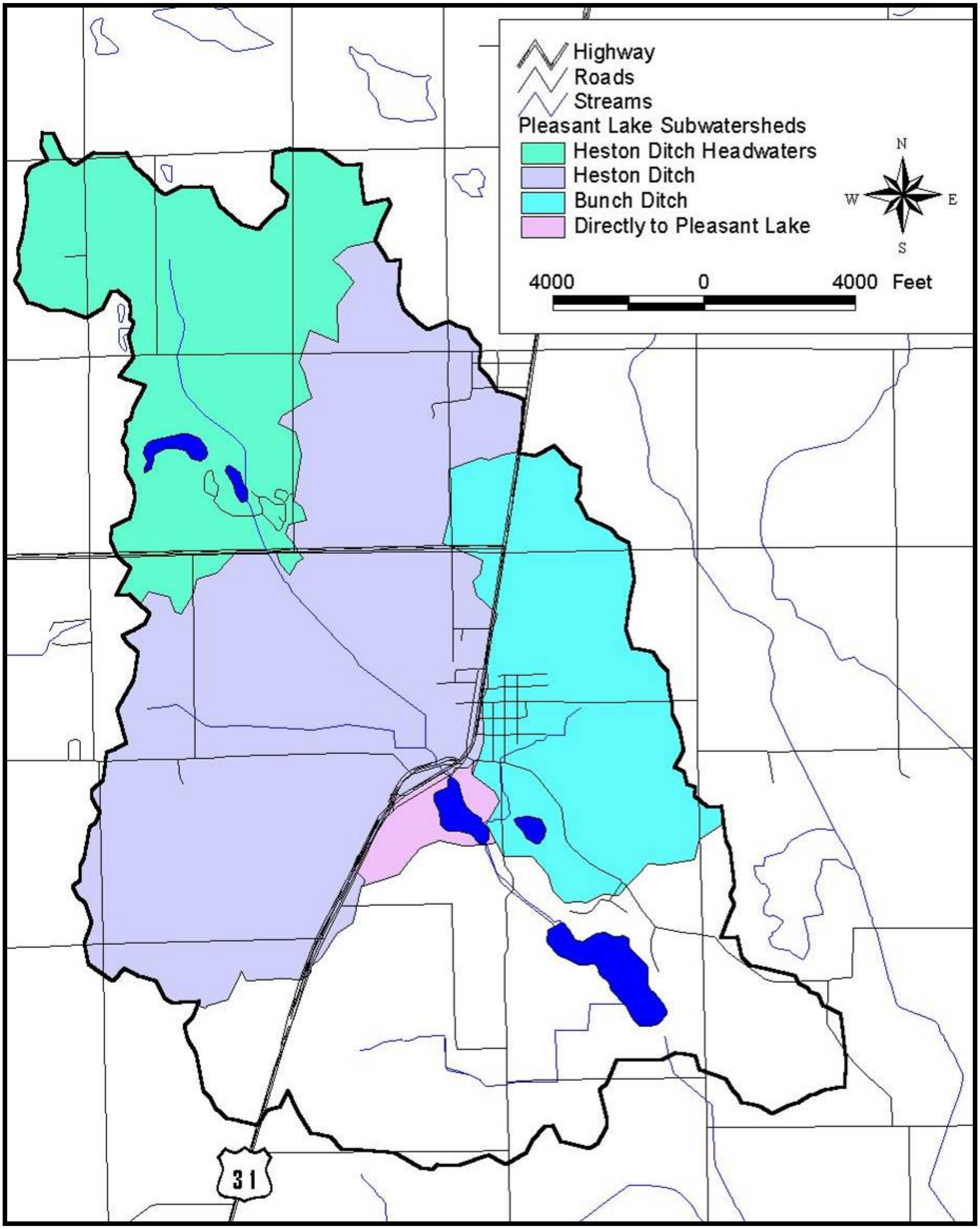

Figure 5. Pleasant Lake subwatersheds.
Source: See Appendix A. Scale: 1"=4,000'.

2.2 Climate

2.2.1 Indiana Climate

Indiana's climate can be described as temperate with cold winters and warm summers. The National Climatic Data Center summarizes Indiana weather well in its 1976 Climatology of the United States document no. 60: "Imposed on the well known daily and seasonal temperature fluctuations are changes occurring every few days as surges of polar air move southward or tropical air moves northward. These changes are more frequent and pronounced in the winter than in the summer. A winter may be unusually cold or a summer cool if the influence of polar air is persistent. Similarly, a summer may be unusually warm or a winter mild if air of tropical origin predominates. The action between these two air masses of contrasting temperature, humidity, and density fosters the development of low-pressure centers that move generally eastward and frequently pass over or close to the state, resulting in abundant rainfall. These systems are least active in midsummer and during this season frequently pass north of Indiana" (National Climatic Data Center, 1976). Prevailing winds in Indiana are generally from the southwest but are more persistent and blow from a northerly direction during the winter months.

2.2.2 Pleasant and Riddles Lakes Watershed Climate

The climate of St. Joseph County is characteristic of northern Indiana possessing warm summers and cold and snowy winters. However, St. Joseph County climate is modified by the presence and location of Lake Michigan, which generally results in increased cloudiness and snow and rainfall and reduced temperature extremes in both the summer and winter than occurs in counties further south or west. Winters in St. Joseph County typically provide enough precipitation, in the form of snow, to supply the soil with sufficient moisture to minimize drought conditions when the hot summers begin. Winters are cold in St. Joseph County, averaging 35º F (1.5º C), while summers are warm, averaging 83º F (28.3º C). St. Joseph County's highest recorded temperature was 109º F (42.8º C) on July 24, 1934. Mild drought conditions occur occasionally during the summer when evaporation is highest. Historic data from 1921 to 1960 suggest that the growing season (defined as days with an air temperature higher than 40º F or 4.4º C) in St. Joseph County is typically 166 days long (Benton, 1977). The last day of freezing temperatures in spring usually occurs around May 3, while the first freezing temperature in the fall occurs around October 16. The average annual precipitation is 39.7 inches (100.8 cm). Table 3 displays average annual precipitation data for St. Joseph County as well as precipitation data for 2005. In total, more than 9 inches (22.8 cm) less precipitation fell in St. Joseph County in 2005 than did in the 30-year period of record.

Table 3. Monthly rainfall data for year 2005 as compared to average monthly rainfall. Current data (2005) is based on rainfall as measured in North Liberty, Indiana; averages are based on available weather observations taken during the years of 1971-2000.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
2005	6.27	2.49	1.86	1.14	1.11	2.36	3.27	2.61	5.00	1.03	2.60	0.65	30.39
St. Joseph	2.27	1.98	2.89	3.62	3.50	4.19	3.73	3.98	3.79	3.27	3.39	3.09	39.70

Source: Purdue Applied Meteorology Group, 2005.

Although, precipitation amounts for 2005 approximate normal amounts for St. Joseph County over the 30-year period from 1971 to 2000, total precipitation was nearly 9 inches (22.8 cm) below normal for the Pleasant and Riddles lakes watershed. The National Weather Service indicated that the summer of 2005 was warmer and drier than is typical for much of northern Indiana (Hitchcock, 2005). Dry weather in the spring led to lower than normal soil moisture content. This, coupled with persistent warm, humid air masses that migrated into northern Indiana, created a situation where heat from the sun warmed the ground and air rather than evaporating moisture from the soil's surface. Additionally, the majority of precipitation events throughout the summer occurred as thunderstorms, which creates extremely variable rainfall total across northern Indiana. The National Weather Service (2005) documented a drought that covered northern Indiana for much of the summer (Figure 6). For South Bend, temperatures averaged 2.9 degrees higher than normal and ranked as the fifth warmest summer on record since 1939. June averaged 4.8 degrees above normal and ranked as the 3rd warmest June on record, while July averaged 1.5 degrees above normal or the 14th warmest July on record. August averaged 2.3 degrees above normal and ranked as the 11th warmest August on record. Precipitation followed similar patterns with 2.12 inches (5.4 cm) less rain than normal in June, 0.27 inches (0.7 cm) less rain than normal in July, and 1.78 inches (4.5 cm) less rain than normal in August (Hitchcock, 2005). Stream channels were relatively low all summer within the Pleasant and Riddles Lakes watershed.

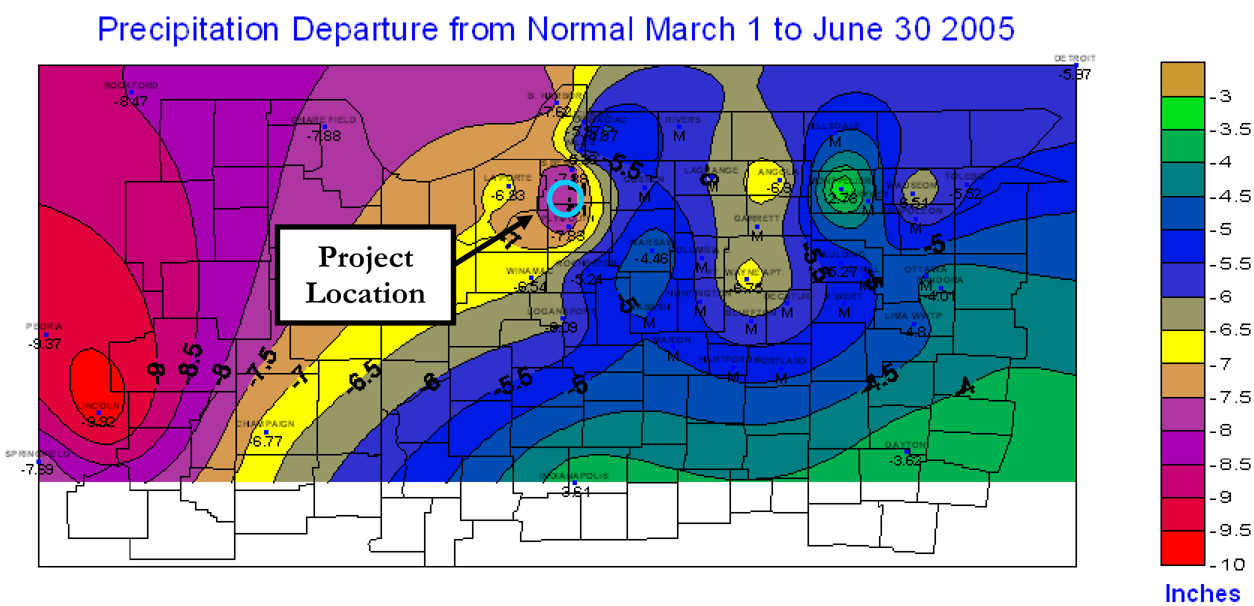

Figure 6. Drought conditions present in northern Indiana in 2005.
Source: National Weather Service, 2005.

2.3 Geology

The advance and retreat of the glaciers in the last ice age shaped much of the landscape observed in Indiana today. As the glaciers moved, they laid thick till material, or ground moraine, over much of the northern two thirds of the state. This ground moraine left by the glaciers covers much of the central portion of the state. In the northern portion of the state, ground moraines, end moraines, lake plains, and outwash plains create a more geologically diverse landscape compared to the central portion of the state. End moraines, formed by the layering of till material when the rate of glacial retreat equaled the rate of glacial advance, add topographical relief to the landscape. Distinct glacial lobes, such as the Michigan Lobe, Saginaw Lobe, and the Erie Lobe, left several large, distinct end moraines, including the Valparaiso Moraine, the Maxinkuckee Moraine, and the Packerton Moraine, scattered throughout the northern portion of the state. Glacial drift and ground moraines cover flatter, lower elevation terrain in northern Indiana. Major rivers in northern Indiana cut through sand and gravel outwash plains. These outwash plains formed as the glacial meltwaters flowed from retreating glaciers, depositing sand and gravel along the meltwater edges. Lake plains, characterized by silt and clay deposition, are present where lakes existed during the glacial age.

Several glacial lobes rather than a single sheet of ice covered northern Indiana during the last glacial age. During the last Wisconsin Age, the Saginaw, Huron/Erie, and Michigan lobes covered much of St. Joseph County. The movement, stagnation, and melting of the Saginaw Lobe of the Wisconsin glacial age is largely responsible for the landscape covering the eastern portion of the Pleasant and Riddles Lakes watershed. The Saginaw glacial lobe moved out of Canada toward the southwest carrying a mixture of Canadian bedrock with it. This lobe traveled as far as approximately five miles south of South Bend before moving southeast across Indiana (Montgomery, 1929). The Packerton and Maxinkuckee moraines mark the extent of the Saginaw Lobe's coverage in northern Indiana. The Michigan Lobe extended east from present day Lake Michigan and overlapped the northwestern corner of St. Joseph County. The Huron/Erie Lobe moved west across northern St. Joseph and Elkhart Counties before moving south along the western St. Joseph and Marshall County lines, then turned east at Logansport, Indiana. The Huron/Erie Lobe is responsible for the range of steep peaks which begin south of South Bend and extend along the western boundary of the Pleasant and Riddles Lakes watershed (Montgomery, 1929). This ridge, which separates the Pleasant and Riddles Lakes watershed from the Potato Creek-Pine Creek watershed, is part of the end moraine left by the Huron/Erie Lobe. Gullies and rugged topography are common along this ridge where some areas are prone to elevation changes of greater than 100 feet (Brown, 2003). Ultimately, the Maxinkuckee Moraine formed when the Huron/Erie and Saginaw Lobes stalled during their last northeasterly retreat (Wayne, 1966). Movement of the Michigan Lobe may have influenced the moraine's formation as well (IDNR, 1990). (Figure 3 shows the areas of greater relief (in orange) associated with the end moraines along the watershed's northern and western boundaries.) A complex mix of glacial silt and clay loam till, mixed drift, and undifferentiated outwash materials lies east of the Maxinkuckee Moraine and covers much of the Pleasant and Riddles Lakes watershed (Figure 7).

Following the retreat of the Wisconsin Age glaciers, water from this outwash plain drained north through an old valley full of silt (Montgomery, 1929). A historical drainage near present day Heston Ditch carried water north toward the Kankakee River Valley (Montgomery, 1929). Water flowed underneath the thick glacial till and outwash material created by the Maxinkuckee Moraine forming peat and muck layers six to ten feet deep (Montgomery, 1929). The formation of this peat coupled with other hydrological changes, including the formation of Heston Ditch, which started as a series of ice blocks that subsequently melted and eventually combined to form the channel (Brown, 2003), eventually directed flow from the Pleasant and Riddles Lakes watershed south to the Yellow River. Pleasant, Riddles, and Fites lakes formed as kettle lakes within the peat-covered, outwash plain. Ultimately, the lakes are underlain by fine-grained sediment and could be short-lived due to peat accumulation (Brown, 2003).

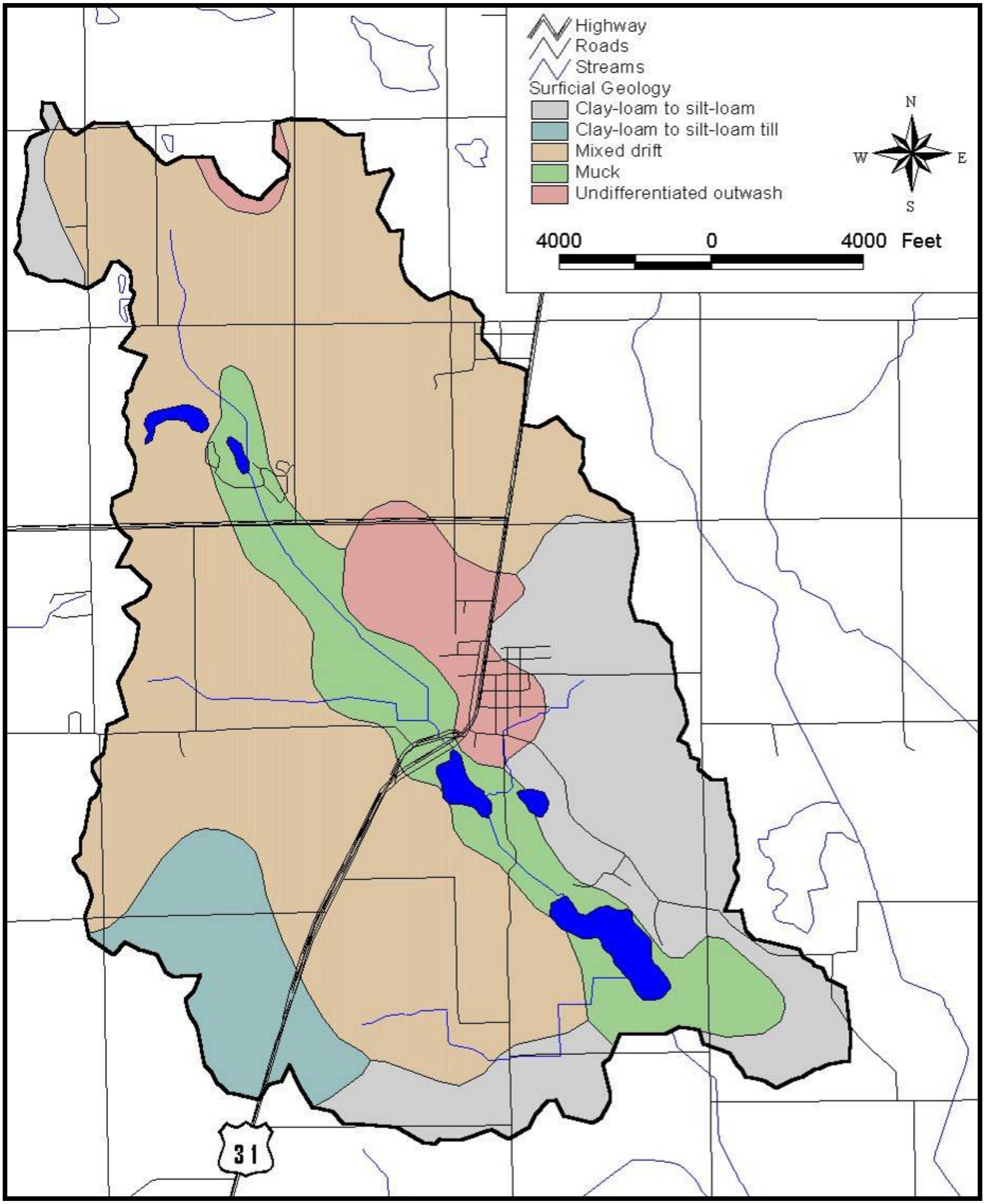

Figure 7. Surficial geology within the Pleasant and Riddles Lakes watershed.
Source: See Appendix A. Scale: 1"=4,000'.

The geology and resulting physiography of the Pleasant and Riddles Lakes watershed typify the physiographic region in which the watershed lies. The Pleasant and Riddles Lakes watershed lies within Malott's Northern Moraine and Lakes Region. Specifically, the watershed lies within the Steuben Morainal Lake Area (Schneider, 1966). Schneider (1966) notes that the landforms common in this diverse physiographic region include till knobs and ice-contact sand and gravel kames, kettle holes and lakes, meltwater channels lined with outwash deposits or organic sediment, valley trains, outwash plains, and small lacustrine plains. Many of these landforms are visible on the Pleasant and Riddles Lakes watershed. Pleasant and Riddles lakes are good examples of kettle lakes that formed in glacial outwash. The flat area extending northwest and southeast of the lakes likely demarcate the extent of an original waterbody that covered much of the watershed many years ago. This waterbody has since been reduced to Pleasant and Riddles lakes. As will be discussed in the *Soils Section*, Houghton muck, a common soil type of aged lakes, is the dominant soil type in this area lending evidence to the idea that this area was once part of a larger lake. Till knobs and kames occur along the watershed's northeastern and northwestern edges. Many other reminders of the watershed's geologic history exist.

The bedrock underlying the watershed's surficial geology is part of the Kankakee Arch. The Kankakee Arch is an upward bow which separates the Lake Michigan Basin to the north from the Kankakee River Basin to the south (IDNR, 1990). The bedrock of the Kankakee Arch underlying the Pleasant and Riddles Lakes watershed is likely Ellsworth shale from the Devonian Period. This shale covers the entire watershed and much of St. Joseph County (Gutschick, 1966).

2.4 Soils

The soil types found in St. Joseph County are a product of the original parent materials deposited by the glaciers that covered this area 12,000 to 15,000 years ago. The main parent materials found in St. Joseph County are glacial outwash and till, lacustrine material, alluvium, and organic materials that were left as the glaciers receded. The interaction of these parent materials with the physical, chemical, and biological variables found in the area (climate, plant and animal life, time, landscape relief, and the physical and mineralogical composition of the parent material) formed the soils of St. Joseph County today.

Pleasant and Riddles Lakes watershed's geological history described in the previous section determined the soil types found in the watershed and is reflected in the major soil associations that covers the Pleasant and Riddles Lakes watershed (Figure 8). Before detailing the major soil associations covering the Pleasant and Riddles Lakes watershed, it may be useful to examine the concept of soil associations. Major soil associations are determined at the county level. Soil scientists review the soils, relief, and drainage patterns on the county landscape to identify distinct proportional groupings of soil units. The review process typically results in the identification of eight to fifteen distinct patterns of soil units. These patterns are the major soil associations in the county. Each soil association typically consists of two or three soil units that dominate the area covered by the soil association and several soil units that occupy only a small portion of the soil association's landscape. Soil associations are named for their dominant components. For example, the Riddles-Miami-Crosier association consists primarily of Riddles loam, Miami loam, and Crosier loam.

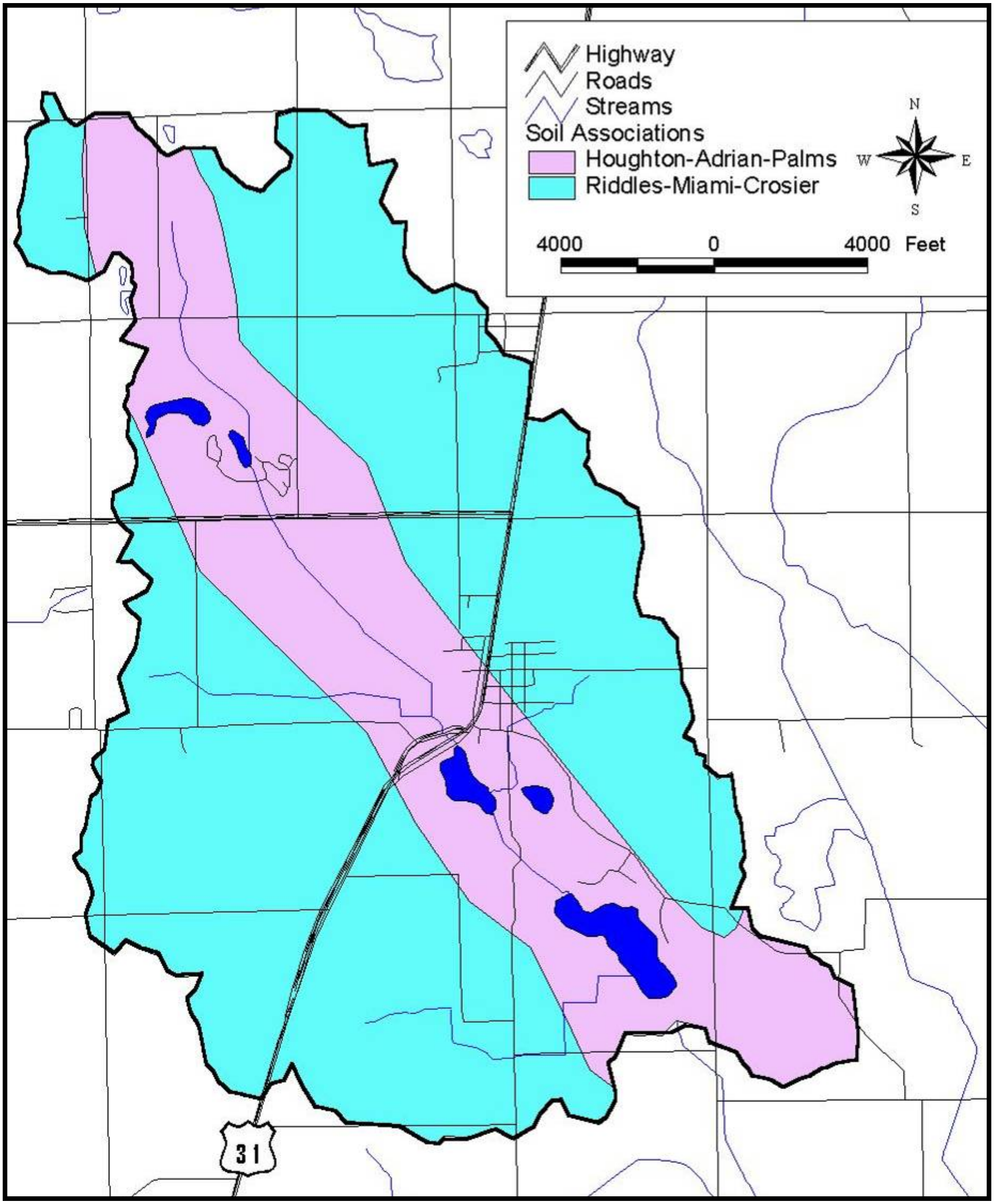

Figure 8. Soil associations in the Pleasant and Riddles Lakes watershed.
Source: See Appendix A. Scale: 1"=4,000'.

Benton (1977) maps two soil associations in the Pleasant and Riddles Lakes watershed: the Riddles-Miami-Crosier soil association and the Houghton-Adrian-Palms soil association (Figure 8). Both soil associations are characteristic of morainal areas in St. Joseph County, such as the Maxinkuckee Moraine. Soils in these associations developed from glacial till parent materials. The Riddles-Miami-Crosier soil association covers the largest portion of the Pleasant and Riddles Lakes watershed. This association is the third most common association in St. Joseph County covering approximately 11% of the county. The Houghton-Adrian-Palms soil association reflects the path of Heston Ditch covering the length of the stream channel and surrounding Pleasant, Fites, and Riddles lakes. The Houghton-Adrian-Palms soil association is slightly less common throughout St. Joseph County than the Riddles-Miami-Crosier association. The Houghton-Adrian-Palms soil association covers approximately 10% of the county.

As indicated above, the Riddles-Miami Crosier association is relatively common in St. Joseph County, covering approximately 11% of the county. This association covers the northeastern and southwestern portions of the Pleasant and Riddles Lakes watershed. This soil association is characterized by well drained to somewhat poorly drained soils that formed on till plains. Riddles soils account for 44% of the soils in this association, while Miami and Crosier soils account for 14% and 12%, respectively. All three soils possess moderately fine textured loam surface layers overlying clay loam and loam subsoils. Minor components of this soil association include Brookston loam, Hillsdale sandy loam, Martinsville loam, Rensselaer loam, and Whitaker loam soils. Erosion is a concern with the Riddles and Miami portions of this soil association on steeply sloped areas, while wetness is the greatest limitation associated with Crosier soils. Utilizing winter crops or maintaining crop residues improves organic matter retention and reduces soil erosion. Like many of the soil association located within St. Joseph County, the Riddles-Miami-Crosier association is moderately to severely limited for septic system usage. Severe limitations occur on Riddles and Miami soils with slopes greater than 12% and within all Crosier soils, which possess a seasonal high water table and moderate to slow permeability.

The Houghton-Adrian-Palms soil association borders the shorelines of Pleasant and Riddles Lake extending northwest and southeast along the mainstem of Heston Ditch. Very poorly drained, nearly level muck soils dominate the Houghton-Adrian-Palms soil association. These soils developed from partially decaying organic matter that accumulated in depressional areas on lake plains and till plains. Generally, Houghton soils account for 36% of the association, while Adrian soils cover 34% of the association. Palms soils account for an additional 10% of the association. Minor components of the association include Edwards muck, Maumee mucky loamy sand, and Rensselaer mucky loam. Houghton soils are deep with black and reddish-brown muck extending to a depth of 45 inches (114.3 cm) or more. Adrian soils contain layers of muck and sand overlying fine sand. Palms soils possess muck, loam, and clay loam layers which lie over sandy loam subsoil. When drained, soils in this association can be utilized for agriculture. Typically, corn or soybeans are grown on soils of the Houghton-Adrian-Palms soil association; however, specialty crops, such as cabbage, onions, mint, or potatoes, are also grown on this association throughout the county. Soils in this association have severe limitations for use as septic system absorption fields due to wetness, while wind erosion limits the usability of these soils for row crop agriculture when drained.

Soils in the watershed, and in particular their ability to erode or sustain certain land use practices, can impact the water quality of lakes and streams in the watershed. The dominance of Riddles and Miami soils across the Pleasant and Riddles Lakes watershed suggests much of the watershed is prone to erosion; common erosion control methods should be implemented when the land is used for agriculture or during residential development to protect waterbodies in the Pleasant and Riddles Lakes watershed. Areas immediately adjacent to Pleasant and Riddles Lakes or located outside of the incorporated boundaries of Lakeville are most likely to be developed for residential use, or could be in the future. Even with the close proximity of Lakeville, the closest town which maintains a sewer system, septic systems will likely be used to treat residential waste around the developed areas adjacent to Pleasant and Riddles Lakes. The coupling of moderate to high density residential land use with soils that are poorly suited for treating septic tank effluent is of concern for water quality in the Pleasant and Riddles Lakes watershed. More detailed discussion of highly erodible soils and soils used to treat septic tank effluent in the Pleasant and Riddles Lakes watershed follows below.

2.4.1 Highly Erodible Soils

Soils that erode from the landscape are transported to waterways where they degrade water quality, interfere with recreational uses, and impair aquatic habitat and health. In addition, such soils carry attached nutrients, which further impair water quality by increasing production of plant and algae growth. Soil-associated chemicals, like some herbicides and pesticides, can kill aquatic life and damage water quality.

Highly erodible and potentially highly erodible are classifications used by the Natural Resources Conservation Service (NRCS) to describe the potential of certain soil units to erode from the landscape. The NRCS examines common soil characteristics such as slope and soil texture when classifying soils. The NRCS maintains a list of highly erodible soil units for each county. Table 4 lists the soil units in the Pleasant and Riddles Lakes watershed that the NRCS considers to be highly erodible and potentially highly erodible.

Highly erodible and potentially highly erodible soil units cover portions of the Pleasant and Riddles Lakes watershed. Riddles, Martinsville, Miami, Oshtemo, and Hillsdale complex soils cover isolated pockets of the watershed. Areas of the watershed that are mapped in these soil units and have gentle slopes are considered moderately limited for agricultural production. As slope increases, the severity of the limitation increases. Some steeply sloped Oshtemo, Riddles, and Hillsdale soils are considered unsuitable for agricultural production due to erosion hazard. The erosion hazard likely also applies to residential development on these soils.

As Figure 9 indicates, potentially highly erodible soils cover approximately 13% (1,037.7 acres or 419.9 ha) of the Pleasant and Riddles Lakes watershed. This acreage is spread throughout the watershed and, in many cases, borders the floodplain of Heston Ditch. Highly erodible soil exists on approximately 242 acres (97.59 ha or approximately 3%) of the watershed. Highly erodible soils are generally located adjacent to Heston Ditch's floodplain northwest of Lakeville. A few small patches of highly erodible soils are also located west and southwest of Riddles Lake. Additionally, a small portion of the southwestern shoreline of Riddles Lake is mapped as highly erodible or potentially highly erodible. It is especially important that best management practices (BMPs) are utilized during residential development projects along this portion of the shoreline. This will ensure that erosion along this shoreline remains minimal.

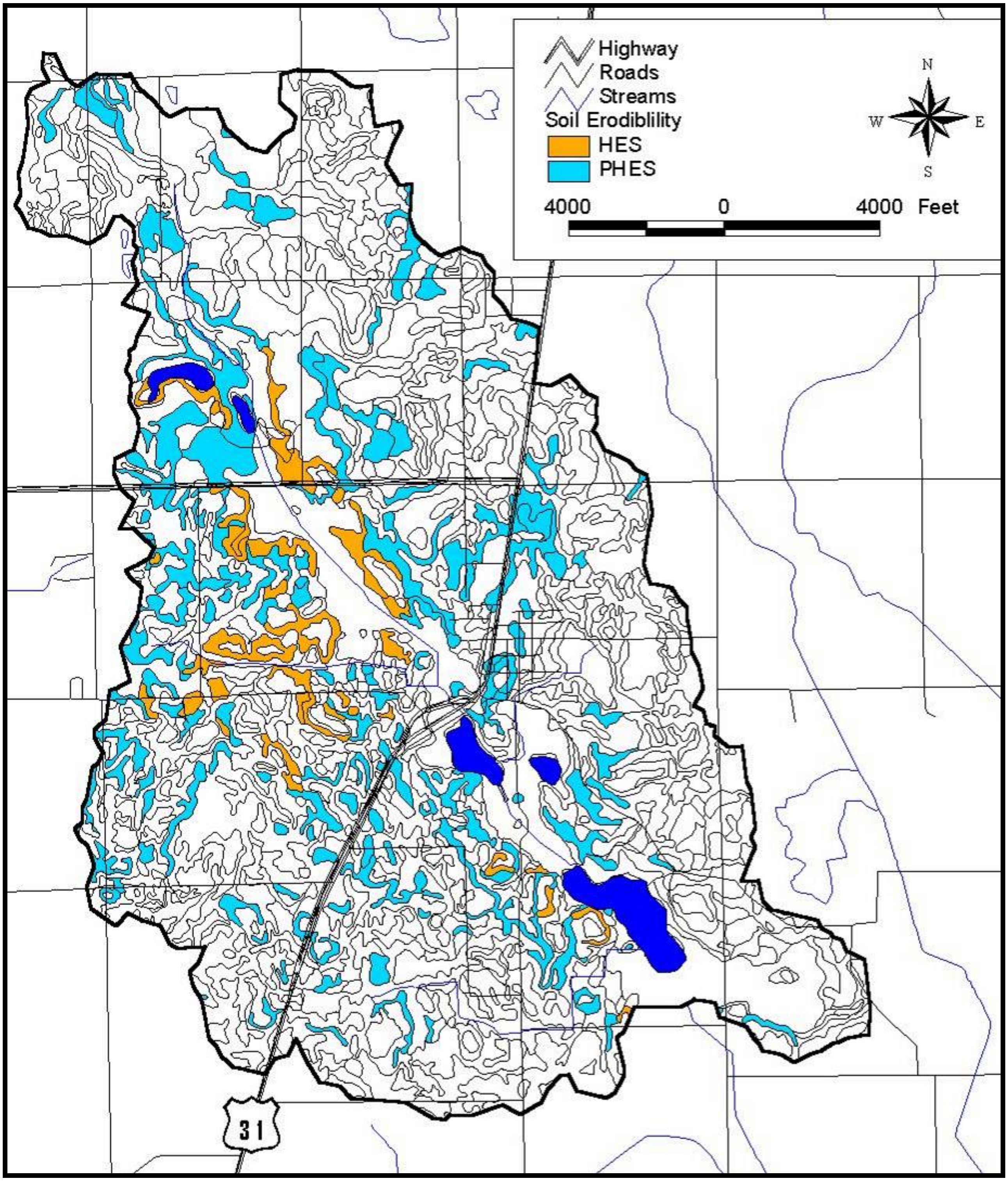

Figure 9. Highly erodible and potentially highly erodible soils within the Pleasant and Riddles Lakes watershed.
Source: See Appendix A. Scale: 1"=4,000'.

Table 4. Highly erodible and potential highly erodible soils units in the Pleasant and Riddles Lakes watershed.

Soil Unit	Status	Soil Name	Soil Description
HknC2	PHES	Hillsdale-Oshtemo sandy loam	5-10% slopes, eroded
HknD2	HES	Hillsdale-Oshtemo sandy loam	10-18% slopes, eroded
MfaB2-MfaC2	PHES	Martinsville loam	1-10% slopes, eroded
MmbC2	PHES	Miami loam	5-10% slopes, eroded
MmdC3	PHES	Miami clay loam	5-10% slopes, severely eroded
MmdD3	HES	Miami clay loam	10-18% slopes, severely eroded
OkrC2	PHES	Oshtemo fine sandy loam	5-10% slopes, eroded
OkrD	HES	Oshtemo fine sandy loam	10-18% slopes
RoqC2	PHES	Riddles-Metea complex	5-10% slopes, eroded
RoqD2	HES	Riddles-Metea complex	10-18% slopes, eroded

* PHES=Potentially highly erodible soil; HES=Highly erodible soil

2.4.2 Soils Used for Septic Tank Absorption Fields

Nearly half of Indiana's population lives in residences having private waste disposal systems. As is common in many areas of Indiana, septic tanks and septic tank absorption fields are utilized for wastewater treatment outside of Lakeville's corporate boundaries, around Pleasant and Riddles Lakes, and throughout the Pleasant and Riddles Lakes watershed. Additionally, some residents within Lakeville have chosen to not be connected to the sewer system. Septic tank wastewater treatment systems rely on the septic tank for primary treatment to remove solids and the soil for secondary treatment to reduce the remaining pollutants in the effluent to levels that protect surface and groundwater from contamination. The soil's ability to sequester and degrade pollutants in septic tank effluent will ultimately determine how well surface and groundwater is protected.

A variety of factors can affect a soil's ability to function as a septic absorption field. Seven soil characteristics are currently used to determine soil suitability for on-site sewage disposal systems: position in the landscape, slope, soil texture, soil structure, soil consistency, depth to limiting layers, and depth to seasonal high water table (Thomas, 1996). The ability of soil to treat effluent (waste discharge) depends on four factors: the amount of accessible soil particle surface area, the chemical properties of the soil particle's surface, soil conditions like temperature, moisture, and oxygen content, and the types of pollutants present in the effluent (Cogger, 1989).

The amount of accessible soil particle surface area depends both on particle size and porosity. Because they are smaller, clay particles have a greater surface area per unit volume than silt or sand; and therefore, a greater potential for chemical activity. However, soil surfaces only play a role if wastewater can contact them. Soils of high clay content or soils that have been compacted often have few pores that can be penetrated by water and are not suitable for septic systems because they are too impermeable. Additionally, some clays swell and expand on contact with water closing the larger pores in the profile. On the other hand, very coarse soils may not offer satisfactory effluent treatment because the water can travel rapidly through the soil profile. Soils located on sloped land also may have difficulty in treating wastewater due to reduced contact time.

Chemical properties of the soil surfaces are also important for wastewater treatment. For example, clay materials have imperfections in their crystal structure which gives them a negative charge along their surfaces. Due to their negative charge, they can bond cations of positive charge to their surfaces. However, many pollutants in wastewater are also negatively charged and are not attracted to the clays. Clays can help remove and inactivate bacteria, viruses, and some organic compounds.

Environmental soil conditions influence the microorganism community which ultimately carries out the treatment of wastewater. Factors like temperature, moisture, and oxygen availability influence microbial action. Excess water or ponding saturates soil pores and slows oxygen transfer. The soil may become anaerobic if oxygen is depleted. Decomposition process (and therefore, effluent treatment) becomes less efficient, slower, and less complete if oxygen is not available.

Many of the nutrients and pollutants of concern are removed safely if a septic system is sited correctly. Most soils have a large capacity to hold phosphate. On the other hand, nitrate (the end product of nitrogen metabolism in a properly functioning septic system) is very soluble in soil solution and is often leached to the groundwater. Care must be taken in siting the system to avoid well contamination. Nearly all organic matter in wastewater is biodegradable as long as oxygen is present. Pathogens can be both retained and inactivated within the soil as long as conditions are right. Bacteria and viruses are much smaller than other pathogenic organisms associated with wastewater; and therefore, have a much greater potential for movement through the soil. Clay minerals and other soil components may adsorb bacteria and viruses, but retention is not necessarily permanent. During storm flows, bacteria and viruses may become resuspended in the soil solution and transported throughout the soil profile. Inactivation and destruction of pathogens occurs more rapidly in soils containing oxygen because sewage organisms compete poorly with the natural soil microorganisms, which are obligate aerobes requiring oxygen for life. Sewage organisms live longer under anaerobic conditions without oxygen and at lower soil temperatures because natural soil microbial activity is reduced.

Taking into account the various factors described above, the NRCS has ranked each soil series in the Pleasant and Riddles Lakes watershed in terms of its limitations for use as a septic tank absorption field. Each soil series is placed in one of three categories: slightly limited, moderately limited, or severely limited. Use of septic absorption fields in moderately or severely limited soils generally requires special design, planning, and/or maintenance to overcome the limitations and ensure proper function. Figure 10 displays the septic tank suitability of soils throughout the Pleasant and Riddles Lakes watershed, while Table 5 lists the soils located within the watershed and their associated properties. Soils severely limited for use a septic tank absorption fields cover nearly 52% of the watershed (3,992 acres or 1,616 ha), while moderately limited soils cover an additional 46% of the watershed (3,583 acres or 1,450 ha). Less than 2% of the Pleasant and Riddles Lakes watershed is covered by soils that are only slightly limited for use as septic tank absorption fields.

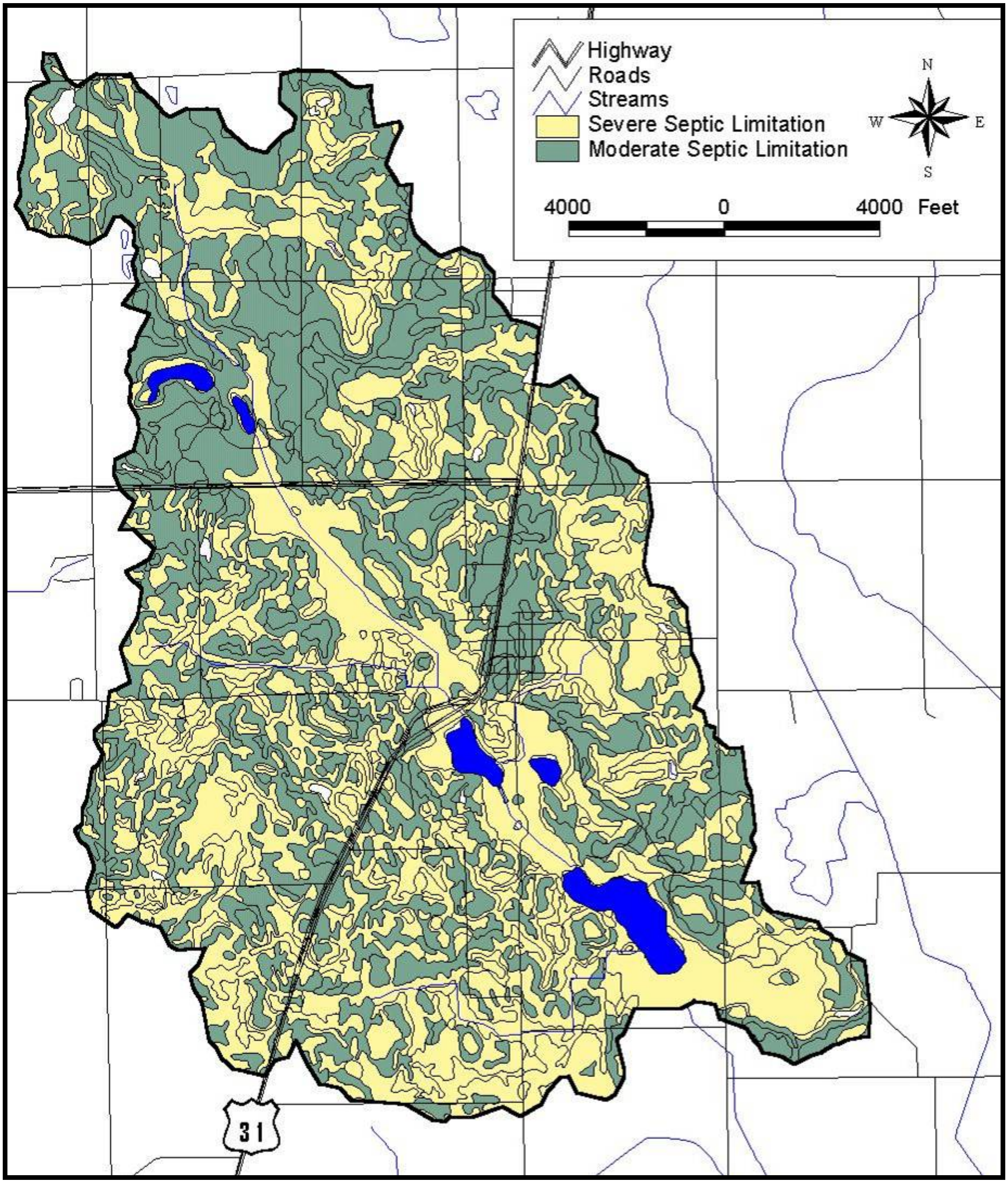

Figure 10. Soil septic tank suitability within the Pleasant and Riddles Lakes watershed.
Source: See Appendix A. Scale: 1"=4,000'.

Table 5. Soil septic tank suitability within the Pleasant and Riddles Lakes watershed.

Symbol	Name	Depth to High Water Table	Suitability for Septic Tank Absorption Field
AbhAN	Adrian muck	0-1 ft.	Severe: poor filter, ponding, seasonal high water table
BbmA	Baugo silt loam	1-3 ft.	Severe: poor filter, seasonal high water table
BuuA	Brookston loam	0-1 ft.	Severe: ponding, seasonal high water table, percs slowly
CnbB	Coloma sand	>6 ft.	Severe: poor filter
CvdA-CvdB	Crosier loam	1-3 ft.	Severe: seasonal high water table
DcrA	Del Rey silty clay loam	1-3 ft.	Severe: seasonal high water table
GczA	Gilford sandy loam	0-1 ft.	Severe: ponding, poor filter, seasonal high water table
HkkA-HkkB	Hillsdale sandy loam	>6 ft.	Moderate: percs slowly
HknC2	Hillsdale-Oshtemo sandy loam	>6 ft.	Moderate: percs slowly; Severe: poor filter
HknD2	Hillsdale-Oshtemo sandy loam	>6 ft.	Moderate: percs slowly; Severe: slope, poor filter
HtbAN; HtbAU	Houghton muck	0-1 ft.	Severe: ponding, seasonal high water table, subsidence
MfaA	Martinsville loam	>6 ft.	Moderate: percs slowly
MfaB2-MfaC2	Martinsville loam	>6 ft.	Moderate: percs slowly
MmbC2	Miami loam	2-3.5 ft.	Severe: seasonal high water table
MmdC3	Miami clay loam	2-3.5 ft.	Severe: seasonal high water table, slope
MmdD3	Miami clay loam	2-3.5 ft.	Severe: seasonal high water table, slope
MouA	Milford silty clay loam	2-3.5 ft.	Severe: ponding, seasonal high water table, percs slowly
MvhAN	Moston muck, drained	0.5-1.3 ft.	Severe: percs slowly, ponding, seasonal high water table
OkrA-OkrB	Oshtemo fine sandy loam	>6 ft.	Severe: poor filter
OkrC2	Oshtemo fine sandy loam	>6 ft.	Severe: poor filter
OkrD	Oshtemo fine sandy loam	>6 ft.	Severe: poor filter, slope
PaaAN; PaaAU	Palms muck	0-1 ft.	Severe: ponding, seasonal high water table, subsidence
Pmg	Pits, Gravel	--	--
PxlA	Psammaquents	0.5-1.35 ft.	Severe: seasonal high water table
RenA	Rensselaer mucky loam	0-1 ft.	Severe: percs slowly, ponding, seasonal high water table
ReyA	Rensselaer loam	0-1 ft.	Severe: percs slowly, ponding, seasonal high water table
RopA-RopB	Riddles-Oshtemo fine sandy loam	>6 ft.	Moderate: percs slowly; Severe: poor filter
RoqB	Riddles-Metea complex	>6 ft.	Moderate: percs slowly; Severe: poor filter
RoqC2	Riddles-Metea complex	>6 ft.	Moderate: percs slowly; Severe: poor filter

Symbol	Name	Depth to High Water Table	Suitability for Septic Tank Absorption Field
RoqD2	Riddles-Metea complex	>6 ft.	Moderate: percs slowly; Severe: poor filter, slope
SdzA	Selfridge-Crosier complex	1-3 ft.	Severe: percs slowly, poor filter, seasonal high water table
TxuB	Tyner loamy fine sand	>6 ft.	Severe: poor filter
WrxAN	Wunabuna silt loam, drained	0-1 ft.	Severe: ponding, seasonal high water table
WtbA	Whitaker loam	0.5-1.7 ft.	Severe: seasonal high water table
WujB	Williamstown-Moon complex	1.5-2.5 ft.	Severe: percs slowly, seasonal high water table

Source: NRCS, 2004.

While all septic system use in the Pleasant and Riddles Lakes watershed has the potential to impact the water quality of Pleasant and Riddles Lakes, the ability of the soil immediately adjacent to each of these lakes to treat septic effluent has a more direct effect on the lakes' water quality than the ability of the soil in other areas of the watershed. For example, the soils directly adjacent to the Pleasant Lake have a more direct effect on Pleasant Lake than the soils in other areas of the watershed. Likewise, the soils directly adjacent to Riddles Lake have a more direct effect on the water quality within Riddles Lake. Therefore, the following discussion focuses on the soils adjacent to Pleasant, Fites, and Riddles Lakes, respectively.

Pleasant and Fites Lakes

Figure 11 shows the soil units surrounding Pleasant and Fites Lakes, while Table 6 summarizes the soils' suitability for use as septic tank absorption fields. Following Table 6 is a short description of the soils listed in the table.

Table 6. Soil types adjacent to Pleasant and Fites Lakes and their suitability to serve as a septic tank absorption field.

Symbol	Name	Depth to High Water Table	Suitability for Septic Tank Absorption Field
HknC2	Hillsdale-Oshtemo sandy loam	>6 ft.	Moderate: percs slowly; Severe: poor filter
HtbAN	Houghton muck	+0.5-1 ft.	Severe: ponding, seasonal high water table, subsidence
OkrB	Oshtemo fine sandy loam	>6 ft.	Severe: poor filter
PaaAN	Palms muck	0-1 ft.	Severe: ponding, seasonal high water table, subsidence

Source: NRCS, 2004.

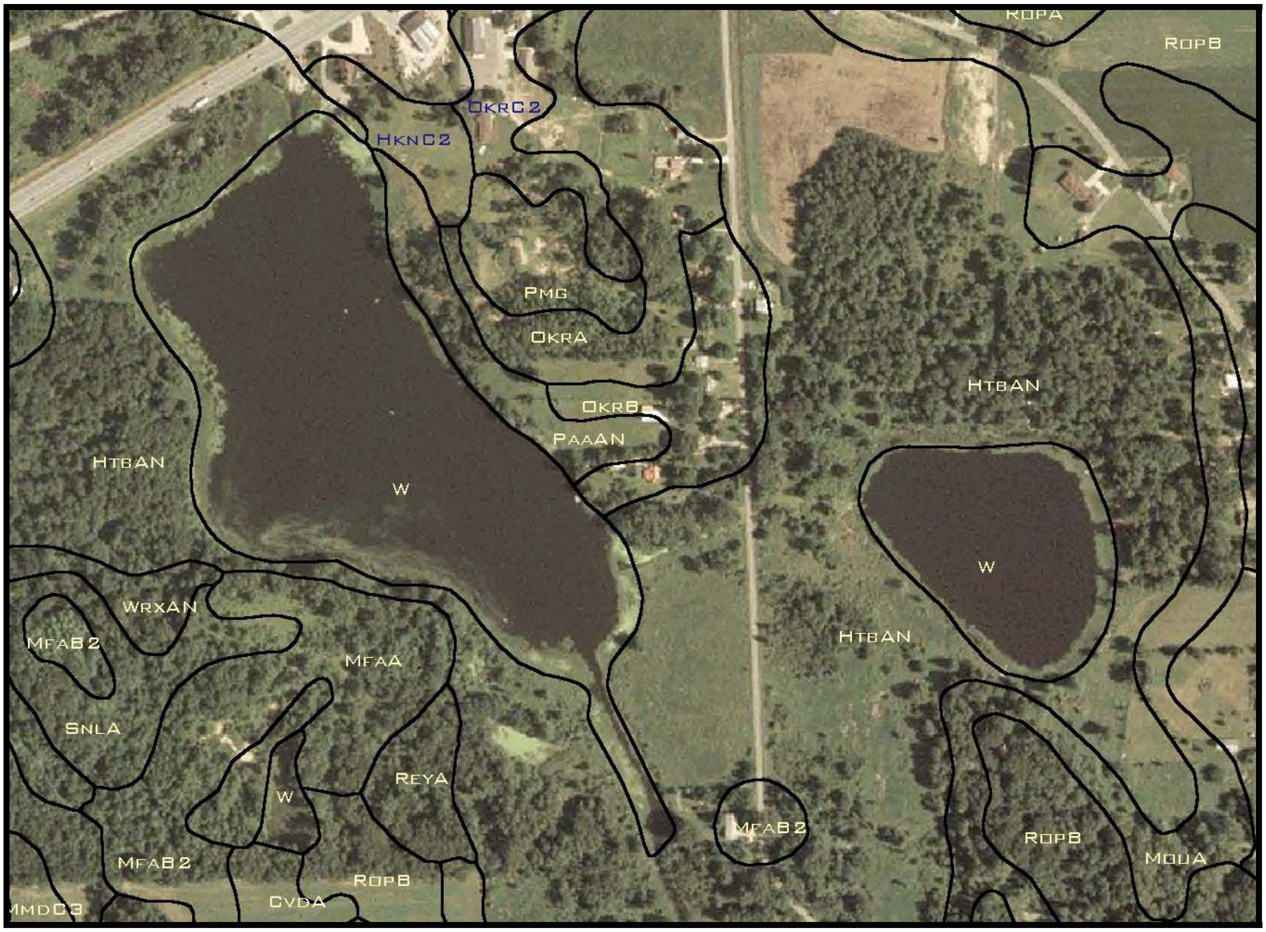

Figure 11. Soil series bordering Pleasant and Fites Lakes.
Source: See Appendix A.

Hillsdale-Oshtemo sandy loam (HknC3) soils are found on gently to strongly sloping hillsides of uplands. Fluid movement through the soil type is moderately slow. The slow permeability and poor filtration capacity generally inhibit complete waste treatment. The slow permeability of Hillsdale-Oshtemo sandy loam soils is a result of soil formation and aging processes.

Houghton muck soils (HtbAN) are nearly level, poorly drained soils. This soil is generally covered by shallow water most of the year, and in some years, it is continually covered. Because of the ponding, this soil is unsuitable for septic tank absorption fields. The NRCS (2003) characterizes this soil as optimal for wildlife habitat but poor for all other uses. These soils are absolutely unsuitable for sanitary facilities due to ponding and permeability issues. Because these soils generally occupy some of the lowest points on the landscape, pumping systems are necessary for adequate drainage.

Palms muck (PaaAN) soils are poorly drained, organic soils found in depressional areas and on outwash plains. Typically, these soils are located adjacent to lakes and streams. Shallow water generally covers them for some portion of the year. The NRCS (2003) characterizes these soils as optimal for wildlife habitat but poor for all other uses. These soils are absolutely unsuitable for sanitary facilities due to ponding and permeability issues. Because these soils generally occupy some of the lowest points on the landscape, pumping systems are necessary for adequate drainage.

Rapid permeability impairs the ability of Oshtemo fine sandy loam (OkrB) soils to serve as septic absorption fields. Permeability is moderate in the subsoil and very rapid in the underlying material. Due to the rapid permeability of these soil types, they do not provide adequate filtering capability for septic tank absorption fields and may cause pollution of the ground water.

As shown in Table 6, all of the soils that border Pleasant and Fites Lakes are moderately to severely limited for use as a septic tank absorption field. Only two residences are located along the shoreline of Pleasant Lake, while the shoreline of Fites Lake remains undeveloped. The residences along Pleasant Lake's shoreline are located within Houghton muck (HtbAN) and Oshtemo fine sandy loam (OkrB) soils. Septic fields placed in these soils typically require larger leach fields to overcome the ponding and permeability issues associated with these soils. Unfortunately, enlarging the existing septic leach fields or creating new leach fields, if sufficient room exists, may be too costly. At a minimum, residents in existing homes should take steps to properly care for their septic tanks annually, avoiding the disposal of household chemicals that may kill soil bacteria, and implementing water conservation measures to alleviate strains on the system. If the remaining portions of the Pleasant Lake shoreline or any portion of the Fites Lake shoreline become developed, then residents should take extra care in septic leach field placement and sizing. However, because these shorelines remain largely undeveloped, septic system leaching does not impact water quality in Pleasant or Fites Lakes at this time.

Riddles Lake
Figure 12 shows the soil units surrounding Riddles Lake, while Table 7 summarizes the soils' suitability for use as septic tank absorption fields. Following Table 7 is a short description of the soils listed in the table.

Table 7. Soil types adjacent to Riddles Lake and their suitability to serve as a septic tank absorption field.

Symbol	Name	Depth to High Water Table	Suitability for Septic Tank Absorption Field
GczA	Gilford sandy loam	0-1 ft.	Severe: ponding, poor filter, seasonal high water table
BuuA	Brookston loam	0-1 ft.	Severe: ponding, seasonal high water table, percs slowly
HtbAN	Houghton muck	0-1 ft.	Severe: ponding, seasonal high water table, subsidence
MmdC3	Miami clay loam	2-3.5 ft.	Severe: seasonal high water table, slope
PaaAN	Palms muck	0-1 ft.	Severe: ponding, seasonal high water table, subsidence
ReyA	Rensselaer loam	0-1 ft.	Severe: percs slowly, ponding, seasonal high water table

Source: NRCS, 2004.

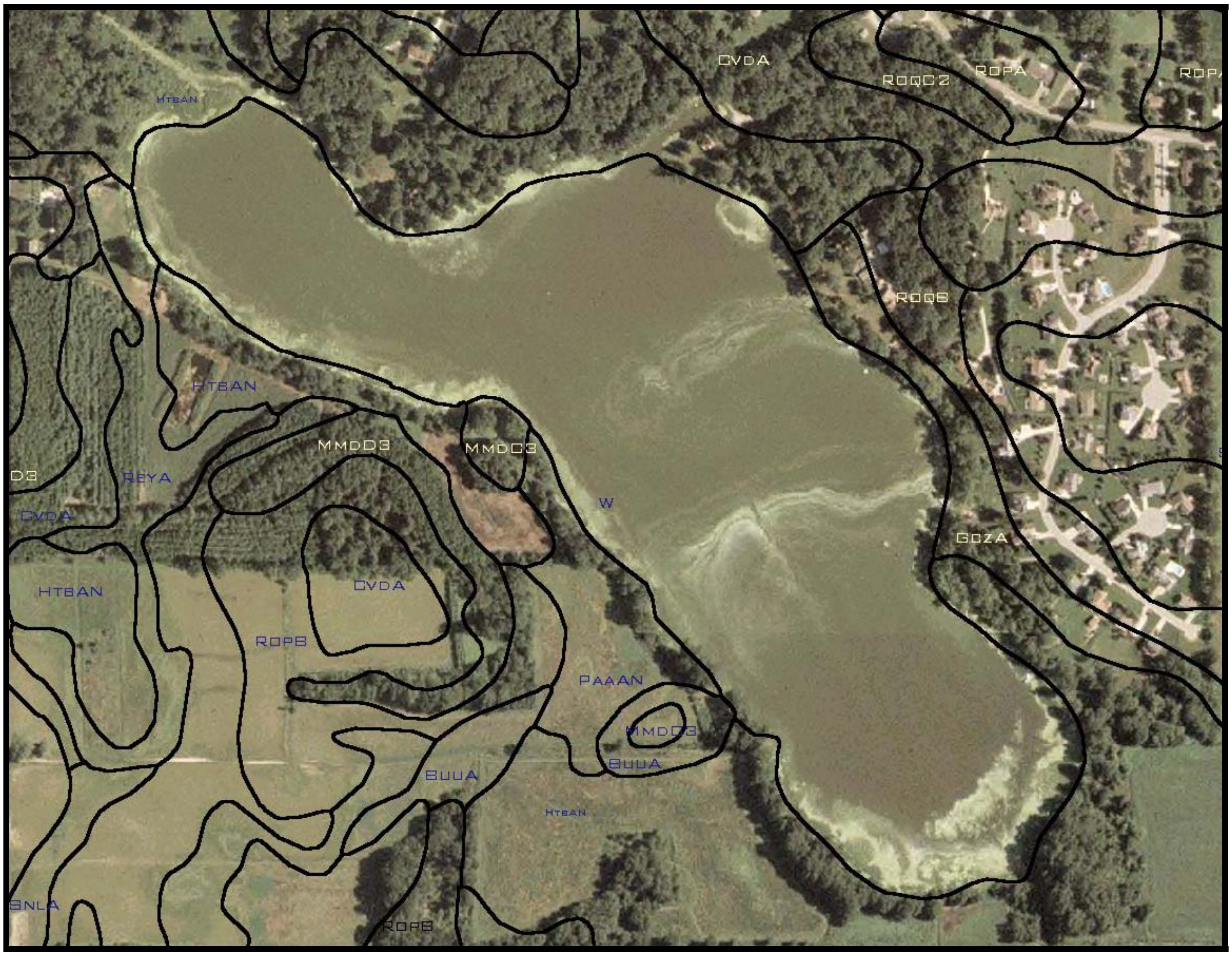

Figure 12. Soil series bordering Riddles Lake.
Source: See Appendix A.

Gilford sandy loam (GczA), Brookston loam (BuuA), and Rensselaer loam (ReyA) soils are very poorly drained soils which are frequently ponded. The ponding severely limits these soils for siting septic tank absorption fields. The water table is typically near the soil surface in winter and spring months. Proper septic system function in these soils is severely limited because the soil tends to remain wet and does not readily absorb liquid waste.

Houghton muck soils (HtbAN) are nearly level, poorly drained soils. This soil is generally covered by shallow water most of the year, and in some years, it is continually covered. Because of the ponding, this soil is unsuitable for septic tank absorption fields. Fortunately, most of the septic systems in the Pleasant and Riddles Lakes watershed are not located in these soils. The NRCS (2003) characterizes this soil as optimal for wildlife habitat by poor for all other uses. These soils are absolutely unsuitable for sanitary facilities due to ponding and permeability issues. Because these soils generally occupy some of the lowest points on the landscape, pumping systems are necessary for adequate drainage.

Seepage of septic effluent due to soil slope and seasonal high water table limits the usage of Miami clay loam (MmdC3) soils as septic tank absorptions fields. Building the system on the ridge top or level contours or using an enlarged absorption field allows for these systems to be used for septic treatment.

Palms muck (PaaAN) soils are poorly drained, organic soils found in depressional areas and on outwash plains. Typically, these soils are located adjacent to lakes and streams. Shallow water generally covers them for some portion of the year. The NRCS (2003) characterizes these soils as optimal for wildlife habitat but poor for all other uses. These soils are absolutely unsuitable for sanitary facilities due to ponding and permeability issues. Because these soils generally occupy some of the lowest points on the landscape, pumping systems are necessary for adequate drainage.

As shown in Table 7, all of the soils surrounding Riddles Lake are moderately to severely limited in their use as a septic tank absorption field. Currently, most of the residences are located at the eastern shoreline with one additional residence in the northwestern corner of the lake. These soils are mapped as Gilford sandy loam (GczA) and Rensselaer loam (ReyA) soils. Septic fields placed in these soils typically require larger leach fields to overcome the ponding and slow permeability. At a minimum, residents in existing homes should take steps to properly care for their septic systems such as pumping their septic tanks annually, avoiding the disposal of household chemicals that may kill soil bacteria, and implementing water conservation measures to alleviate strain on the system.

St. Joseph County Health Department records document multiple (14) failed septic systems within the Pleasant and Riddles Lakes watershed from 1994 to 2001 (St. Joseph County Health Department, personal communication). All of the documented failures are located in soils mapped in the Houghton-Adrian-Palms soil association. As detailed above, Houghton-Adrian-Palms soils possess high water tables, are poorly drained, and are severely limited for use as septic tank absorption fields. Many of the failed septic systems are located along Lake Trail north and east of Riddles Lake. All of these septic systems have been repaired or updated following the documented failure (MWH, 2002). Figures documenting the location of septic system failures and subsequent repairs are included in Appendix B. Montgomery Watson Harza determined that Lakeville and the surrounding area including Pleasant and Riddles Lakes was an area of concern; however, data collected from this vicinity was insufficient to determine if septic system problems were site specific or if they were representative of an area-wide problem (MWH, 2002).

The Town of Lakeville is sited on soils that are moderately to severely limited for septic tank absorption fields. However, the town operates and maintains an individual wastewater treatment facility throughout the year. The facility treats wastewater from 277 homes or 91% of the residences within the incorporated boundaries of Lakeville (MWH, 2002). In order to treat the resident's wastewater, the facility utilizes a stabilization pond treatment system prior to discharging treated effluent. The facility is permitted to discharge 130,000 gallons of treated wastewater to Shidler-Hoffman Ditch, which is located outside of the Pleasant and Riddles Lakes watershed east of Lakeville (MWH, 2002). The facility's permits include concentration and load requirements for total suspended solids, ammonia-nitrogen, pH, biological oxygen demand, and dissolved oxygen. No permit violations were recorded for the facility from January 2004 through June 2005 (USEPA, 2005). However, there is some evidence (discussed in further detail in the Stream Results Section) that the lift stations may be leaking or over-flowing during storm events and not working at full capacity at all times.

2.5 Natural History

Geographic location, climate, topography, geology, soils, and other factors play a role in shaping the native floral (plant) and faunal (animal) communities in a particular area. Various ecologists (Deam, 1921; Petty and Jackson, 1966; Homoya et al., 1985; Omernik and Gallant, 1988) have divided Indiana into several natural regions or ecoregions, each with similar geographic history, climate, topography, and soils. Because the groupings are based on factors that ultimately influence the type of vegetation present in an area, these natural areas or ecoregions tend to support characteristic native floral and faunal communities. Under many of these classification systems, the Pleasant and Riddles Lakes watershed lies at or near the transition between two or more regions. For example, the watershed lies at the western boundary separating Homoya's Northern Lakes Natural Area to the east from the Grand Prairie Natural Area to the west. Similarly, the Pleasant and Riddles Lakes watershed lies in Omernik and Gallant's Central Corn Belt Plains Ecoregion immediately west of Southern Michigan/Northern Indiana Till Plains Ecoregion. As a result, the native floral community of the Pleasant and Riddles Lakes watershed likely consisted of components of neighboring natural areas and ecoregions in addition to components characteristic of the natural area and ecoregion in which it is mapped.

Homoya et. al (1985) noted that prior to European settlement, the region was a mixture of numerous natural community types including bog, fen, marsh, prairie, sedge meadow, swamp, seep spring, lake and deciduous forest. The dry to dry-mesic uplands, like the areas of higher elevation in the western portion of the watershed, were likely forested with red oak, black oak, shagbark hickory, and pignut hickory. More mesic areas, like those along the U.S. 31 corridor, probably harbored beech, sugar maple, black maple, and tulip poplar with sycamore, American elm, red elm, green ash, silver maple, red maple, cottonwood, hackberry, and honey locust dominating the floodplain forests. Historical records support the observation that prior to European settlement of Union Township dense forests vegetated by walnut, oak, ash, and hickory and large tracts of fertile prairie and low swampy marshes covered the Pleasant and Riddles Lakes watershed (Chapman, 1880; IDNR, 1990; Historic Preservation Commission, 2000). Chamberlain (1849) described the area as pleasantly rolling with hickory or burr oak barrens, oak openings, heavy timber, wet or dry prairie, and marsh. Hickory, maple, beech, elm, walnut, butternut, and red and black oak dominated the heavily wooded portions of the region (Chapman, 1880; Howard, 1907; Petty and Jackson, 1966; Omernik and Gallant, 1988; Historic Preservation Commission, 2000). Petty and Jackson (1966) list pussy toes, common cinquefoil, wild licorice, tick clover, blue phlox, waterleaf, bloodroot, Joe-pye-weed, woodland asters, woodland goldenrods, wild geranium, and bellwort as common components of the forest understory in the watershed's region.

Wet habitat (ponds, marshes, and swamps) covered large portions of the Pleasant and Riddles Lakes watershed. Union Township, once considered a useless tract of land, was generally a large pond with isolated tracts of dry land (Chapman, 1880). The hydric soils map indicate that wetland habitat existed throughout much of the Pleasant and Riddles Lakes watershed including most of the eastern portion of the watershed and along the length of Heston Ditch. These wet habitats supported very different vegetative communities than the drier portions of the landscape. Swamp loosestrife, cattails, soft stem bulrush, marsh fern, marsh cinquefoil, pickerel weed, arrow arum, and sedges dominated the marsh habitat throughout the watershed. Swamp habitat likely covered most or all of the shallow depressions in the watershed. Typical dominant swamp species in the area included red and silver maple, green and black ash, and American elm (Homoya et al., 1985).

In the late 1830s, the Michigan Road was constructed from Lake Michigan (via South Bend) to Madison, Indiana. By the mid-1840s, the town of Lakeville had developed as a stopping point between Logansport and South Bend (Howard, 1907). The town continued to develop as the Michigan Southern and Northern Indiana; the Indiana, Illinois, and Iowa; the Vandalia; and the Wabash Railroads connected Lakeville with Chicago, Toledo, and Detroit. By 1880, a sawmill, a gristmill, and several stores cemented Lakeville's place in the growth and development of St. Joseph County (Historic Preservation Commission, 2000).

Development of Union Township was somewhat slower than that observed in and around Lakeville. Many of the soils throughout the township were considered unfavorable for residential or agricultural uses due to heavy timber and marsh cover. Individuals began clearing the rolling hills within the western portion of the township in the 1840s. Forests continued to be cleared and more marshes disappeared as more of Union Township was settled (Chapman, 1880). Laws passed in 1850 aimed at reclaiming the land around the Kankakee River through levee construction and draining the adjacent soils were utilized to regulate drainage in other portions of St. Joseph County, including much of Union Township (Historic Preservation Commission, 2000). Once drained and cleared, the strong, fertile, clay soils created choice farm ground which was soon settled and used to produce wheat, corn, oats, potatoes, and fruit and to raise beef cattle, hogs, and sheep (Benton, 1977). Remnants of natural prairie, forest, and wetland are scattered in isolated patches throughout the area (IDNR, 1990).

2.6 Land Use

Just as soils, climate, and geology shape the native communities within the watershed, how the land in a watershed is used can impact the water quality of a waterbody. Land use can have a significant impact on water quality since different land use types receive different pollutants and have different capacities for retaining and/or assimilating pollutants. For example, residential areas are often subject to high rates of fertilizer application, whereas forests often receive little human-applied fertilizer. Residential areas do not have the same capacity as forests to assimilate pollutants that reach the landscape. Forested and other vegetated landscapes assimilate nutrients that reach these areas via plant growth. Land uses with high amounts of impervious surfaces have reduced, or in extreme cases, no ability to retain or assimilate pollutants.

Pollutants that cannot be assimilated by the landscape leave the landscape during rain events. Researchers have examined the pollutant loss from different landscapes and developed pollutant export coefficients for different landscapes. Pollutant export coefficients are a measure of the rate a pollutant is lost from a landscape per unit area of the landscape. To illustrate how different land types assimilate pollutants, Table 8 presents some mid-range phosphorus export coefficients for different land use types. (Phosphorus was selected for this illustration since it is one of the pollutants of critical concern in lakes. Phosphorus is the nutrient that typically controls algae and rooted plant growth in aquatic ecosystems.) As shown in Table 8, high and low density residential land, commercial land, agricultural land, and golf courses have relatively high phosphorus export rates compared to more natural landscapes such as wetlands, forests, and old fields. The export coefficients provided in Table 8 are simply estimates. The use of best management practices, such as filter strips on agricultural land or stormwater infiltration trenches on commercial land, can reduce the export of pollutants to adjacent waterways or lakes.

Table 8. Mid-range phosphorus export coefficients.

Land Use	Phosphorus Export Coefficient (kg/ha-yr)
Agricultural	1.0
EM/SS Wetland	0.1
Emergent Wetland	0.1
Forested	0.2
High Density Residential	2.5
Low Density Residential	0.8
Open Space	0.2
Open Water	0.0
High Density Commercial	2.5
Low Density Commercial	1.5
Old Field	0.2
Golf Course	1.5

Source: Reckhow et al. 1980 and Reckhow and Simpson, 1980.

Several researchers have also examined the impact of specific urban and suburban land uses on water quality (Bannerman et. al, 1993; Steuer et al., 1997; Waschbusch et al., 2000). Bannerman et al. (1993) and Steuer et al. (1997) found high mean phosphorus concentrations in runoff from residential lawns (2.33 to 2.67 mg/L) and residential streets (0.14 to 1.31 mg/L). These concentrations are well above the threshold at which lakes might begin to experience algae blooms. (Lakes with total phosphorus concentrations greater than 0.03 mg/L will likely experience algae blooms.) Finally, the Center for Watershed Protection has estimated the association of increased levels of impervious surface in a watershed with increased delivery of phosphorus to receiving waterbodies (Caraco and Brown, 2001). Land use directly affects the amount of impervious surface in a watershed. Because of the effect watershed land use has on water quality of the receiving lakes, mapping and understanding a watershed's land use is critical in directing water quality improvement efforts.

2.6.1 Riddles Lake Watershed

Table 9 and Figure 13 present current land use information for the Riddles Lake watershed. (Land use data from the U.S. Geological Survey (USGS) forms the basis of Figure 13. Corrections to the Indiana Land Cover Data Set were made based on 2003 aerial photographs.) Like many Indiana watersheds, agricultural land use dominates the Riddles Lake watershed accounting for approximately 68% of the watershed. Row crop agriculture makes up the greatest percentage of agricultural land use at 53% while pastures or hay vegetate another 15%. Most of the agricultural land in the Riddles Lake watershed and throughout St. Joseph County (USDA, 2002) is used for growing corn and soybeans. Hay, mint, and wheat are also common crop items grown throughout St. Joseph County (Benton, 1977; USDA, 2002). County-wide tillage transect data for St. Joseph County provides an estimate for the portion of cropland in conservation tillage for the Riddles Lake watershed. In St. Joseph County, corn producers utilize no-till methods on 8% of corn fields and some form of reduced tillage on 52% of corn fields (IDNR, 2005b). The percentage of corn fields on which no-till methods were used in St. Joseph County was below the statewide median percentage. In total, St. Joseph County ranks 70th of 92 counties in Indiana in terms of percentage of fields utilizing no-till farming methods for corn production (IDNR, 2005a). St. Joseph County soybean producers used no-till methods on 41% of soybean fields and some form of reduced tillage on 48% of soybean fields in production (IDNR, 2005b). In total, St. Joseph County ranks 76th of 92 counties in Indiana in terms of percentage of fields utilizing no-till farming methods for soybean production (IDNR, 2005a).

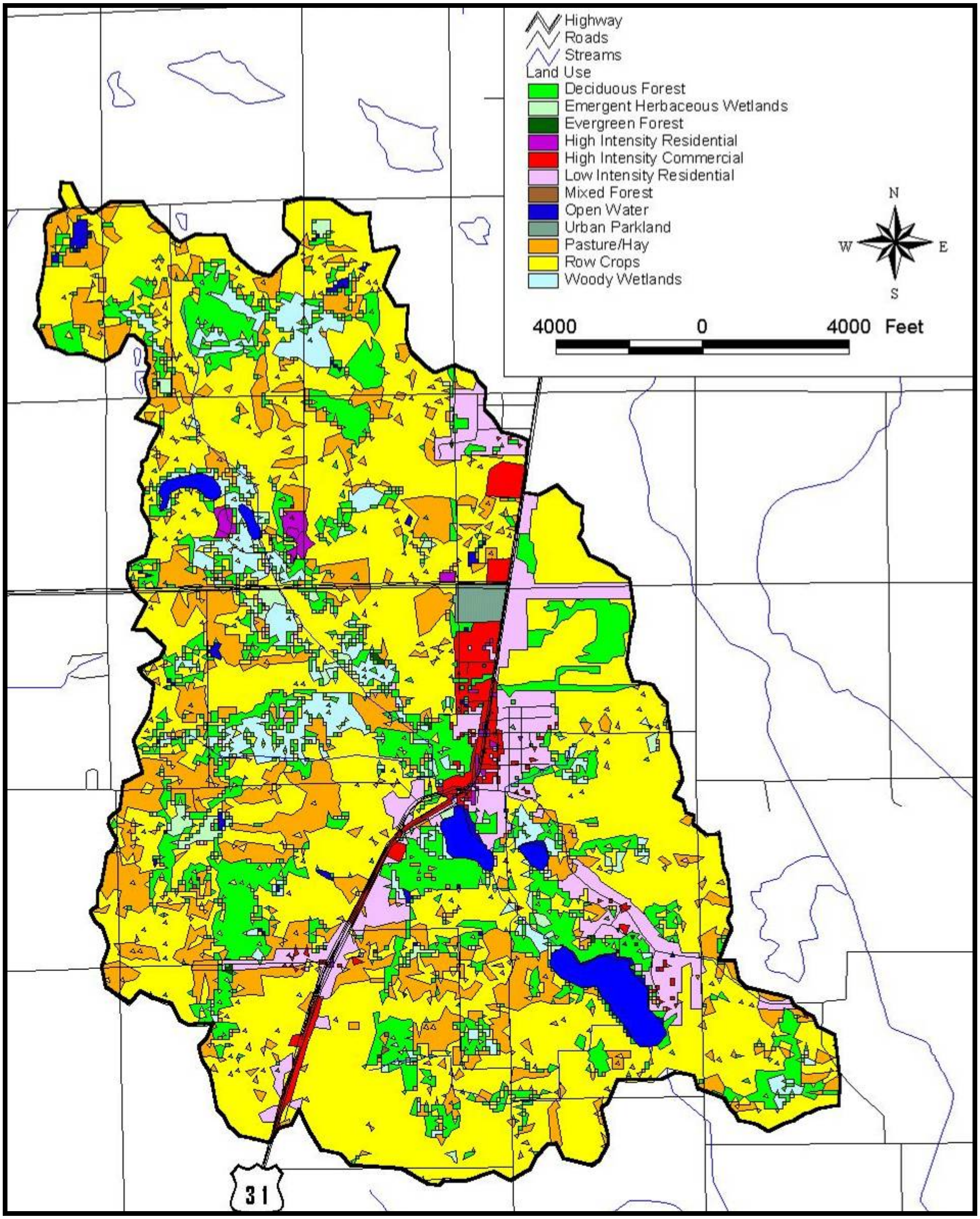

Figure 13. Land use in the Pleasant and Riddles Lakes watershed.
Source: See Appendix A. Scale: 1"=4,000.

Table 9. Detailed land use in the Riddles Lake watershed.

	Area (acres)	Area (ha)	Percent of Watershed
Row Crops	4,082.1	1,652.7	52.8%
Pasture/Hay	1,200.0	485.8	15.5%
Deciduous Forest	1,105.3	447.5	14.3%
Low Intensity Residential	494.5	200.2	6.4%
Woody Wetlands	351.3	142.2	4.5%
High Intensity Commercial	171.4	69.4	2.2%
Open Water	146.6	59.3	1.9%
Emergent Herbaceous Wetlands	101.8	41.2	1.3%
High Intensity Residential	38.2	15.5	0.5%
Other Grasses	32.6	13.2	0.4%
Evergreen Forest	6.6	2.7	0.1%
Mixed Forest	1.0	0.4	<0.1%
Entire Watershed	**7,731.2**	**3,130.0**	**100%**

Remnants of native landscape, including forested areas and wetlands, cover approximately 20% of the watershed. Most of the natural areas are contained in forested and wooded wetland tracts around Pleasant, Riddles, and Fites Lakes; along the length of Heston Ditch; and within the northern portion of the watershed. Smaller wooded and emergent wetlands are scattered throughout the watershed. Open water in the form of Pleasant, Fites, Moon, and Riddles Lakes account for an additional 2% of the watershed.

Approximately 735 acres (297.6 ha or 10%) of the watershed are used for residential or commercial purposes. Much of the residential and commercial land is located within Lakeville, along the northeastern shoreline of Pleasant and Riddles Lakes, or within the U.S. 31 corridor (Figure 13). Low intensity residential areas account for a majority of the residential and commercial development within the watershed. (In the Indiana Land Cover Data Set, the USGS defines low intensity residential areas as those areas which consist largely of single-family homes where impervious surfaces (rooftops, roads, sidewalks, etcetera) cover 30 to 80% of the landscape.) Using this definition, and assuming that impervious surfaces cover approximately 50% of the residential land use (an estimate on the low side of the range), impervious surfaces cover approximately 5% of the watershed. Based on estimates developed by Lee and Toonkel (2003), approximately 3% of the watershed is impervious. These estimates of impervious surface coverage are below the threshold at which the Center for Watershed Protection has found an associated decline in water quality.

Land use within the Riddles Lake watershed is similar to land use across the region. The Riddles Lake watershed supports a slightly lower percentage of land in agricultural use (68%) compared to the Kankakee River Basin (75%; IDNR, 1990). However, the percentage of land in agricultural use is higher than the percentage of St. Joseph County (55%; USDA, 2002). The Riddles Lake watershed contains higher percentages of land use in forest and wetland/open water (14% and 8%, respectively) than the entire Kankakee River Basin (9% and 8%, respectively; IDNR, 1990). However, the Riddles Lake watershed also contains a higher percentage of land in urban uses (10%) than that found in the entire Kankakee River Basin (8%; IDNR, 1990).

2.6.2 Pleasant Lake Watershed

Land use within the Pleasant Lake watershed parallels that of the entire Pleasant and Riddles Lakes watershed. Agricultural land use dominates the Pleasant Lake watershed (Table 10). Row crop agriculture covers approximately 50% of the watershed, while pasture or hay covers an additional 16% of the watershed. Natural landscapes, such as forests and wetlands, account for 15% and 7% of the Pleasant Lake watershed, respectively. Open water in the form of Pleasant, Fites, and Moon Lakes account for approximately 1% of the watershed. Commercial and residential land uses cover the remaining 11% of the watershed.

Table 10. Detailed land use in the Pleasant Lake watershed.

	Area (acres)	Area (ha)	Percent of Watershed
Row Crops	2,806.7	1,136.3	50.1%
Pasture/Hay	893.2	361.6	15.9%
Deciduous Forest	826.6	334.7	14.8%
Low Intensity Residential	380.2	153.9	6.8%
Woody Wetlands	324.2	131.3	5.8%
High Intensity Commercial	143.0	57.9	2.6%
Emergent Herbaceous Wetlands	87.1	35.3	1.6%
Open Water	66.9	27.1	1.2%
High Intensity Residential	38.0	15.4	0.7%
Other Grasses	32.6	13.2	0.6%
Evergreen Forest	5.0	2.0	0.1%
Mixed Forest	0.2	0.1	<0.1%
Entire Watershed	**5,603.6**	**2,268.7**	**100%**

2.7 Wetlands

Because wetlands perform a variety of functions in a healthy ecosystem, they deserve special attention when examining watersheds. Functioning wetlands filter sediments and nutrients from runoff, store water for future release, alleviate flooding, provide an opportunity for groundwater recharge or discharge, and serve as nursery and forage habitat for various fish and wildlife species. By performing these roles, healthy, functioning wetlands often improve water quality and the biological health of streams and lakes located downstream of the wetlands.

The United States Fish and Wildlife Service's (USFWS) National Wetland Inventory (NWI) Map (Figure 14) shows that wetlands and open water cover approximately 11.6% of the Pleasant and Riddles Lakes watershed. In total, wetlands cover approximately 10.1% of the watershed, while open water covers an additional 1.5% of the watershed. (Table 11 presents the acreage of wetlands by type according to the National Wetland Inventory.) Large, contiguous tracts of wetland habitat extend along the length of Heston Ditch from north of State Road 4 south to Pleasant Lake. Forested and emergent wetlands vegetate the western and southern shorelines of Pleasant Lake and extend along the length of Heston Ditch between Pleasant and Riddles Lakes. Emergent, scrub-shrub, and forested wetlands cover much of the area surrounding Fites Lake and extend south toward Heston Ditch. Additional large tracts of wetland habitat are located north of Osborn Road and east and north of the incorporated boundaries of Lakeville. Smaller, non-contiguous wetlands are located in patches throughout the remainder of the watershed.

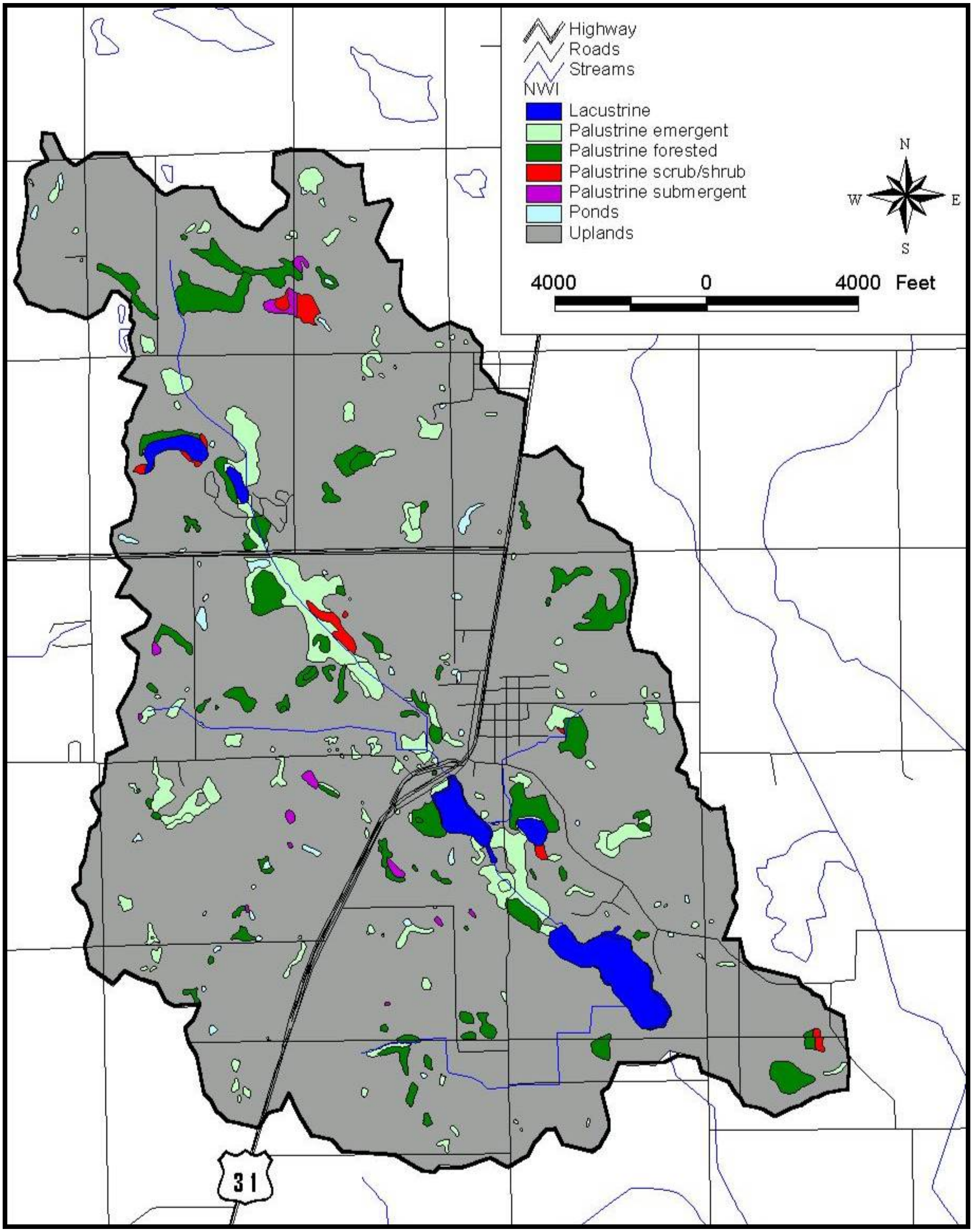

Figure 14. Wetlands in the Pleasant and Riddles Lakes watershed.
Source: See Appendix A. Scale: 1"=4,000'.

Table 11. Acreage and classification of wetland habitat in the Pleasant and Riddles Lakes watershed.

Wetland Type	Area (acres)	Area (hectares)	Percent of Watershed
Emergent Herbaceous	356.0	144.1	4.6%
Forested	329.5	133.4	4.3%
Lake	113.1	45.8	1.5%
Pond	45.2	18.3	0.6%
Scrub/Shrub	35.5	14.4	0.5%
Submerged Herbaceous	19.4	7.8	0.3%
Total Wetlands	**898.6**	**363.8**	**11.6%**

The USFWS NWI data differs in its estimate of wetland habitat acreage in the watershed from the USGS data presented in Table 9 and Figure 13. The USGS Land Cover Data Set suggests that wetlands cover 5.8% of the Pleasant and Riddles Lakes watershed and open water covers an additional 1.5% of the watershed (Table 11). The main difference between the two data sets is the acreage of emergent wetland. The USFWS reports approximately 356 acres (144.1 ha) of emergent wetland habitat located within the Pleasant and Riddles Lakes watershed compared to less than 102 acres (41.2 ha) reported by the USGS. The differences in reported wetland acreage in the watershed reflect the differences in project goals and methodology used by the different agencies to collect land use data.

The U.S. Fish and Wildlife Service estimates an average of 2.6% of the nation's wetlands were lost annually from 1986 to 1997 (Zinn and Copeland, 2005). The IDNR estimates that approximately 85% of the state's wetlands have been filled or drained (IDNR, 1996). The greatest loss occurred in the northern counties of the state such as St. Joseph County. The last glacial retreat in these northern counties left level landscapes dotted with wetland and lake complexes. Development of the land in these counties for agricultural purposes altered much of the natural hydrology, eliminating many of the wetlands.

To estimate the historical coverage of wetlands in the Pleasant and Riddles Lakes watershed, hydric soils in the watershed were mapped in Figure 15. (As noted for the potentially highly erodible soils map, this map is based on the Natural Resources Conservation Service criteria for hydric soils and is not field checked.) Because hydric soils developed under wet conditions, they are a good indicator of the historical presence of wetlands. Comparing the total acreage of wetland (hydric) soils in the watershed (2,025 acres or 819.5 ha) to the acreage of existing wetlands (898.6 acres or 363.6 ha) suggests that nearly 44% of the original wetland acreage exists today. The most significant wetland losses have occurred in the southwestern portion of the watershed south and west of Riddles Lake; along the mainstem of the western branch of Heston Ditch; around existing wetland complexes adjacent to, east, and northeast of Fites Lake; and north of State Road 4. These losses become obvious by comparing Figures 14 and 15.

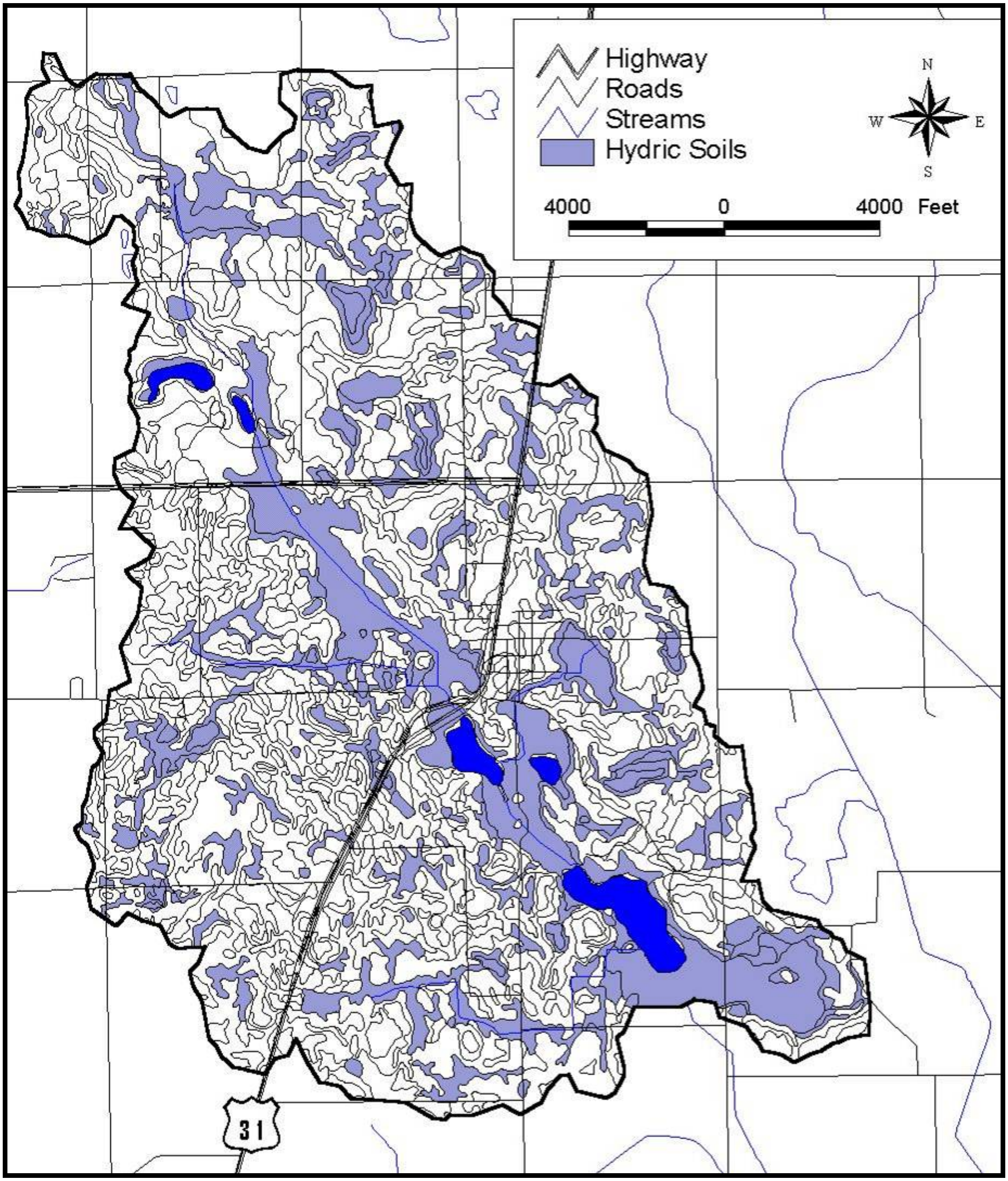

Figure 15. Hydric soils in the Pleasant and Riddles Lakes watershed.
Source: See Appendix A. Scale: 1"=4,000'.

2.8 Natural Communities and Endangered, Threatened, and Rare Species

The Indiana Natural Heritage Data Center database provides information on the presence of endangered, threatened, or rare species; high quality natural communities; and natural areas in

Indiana. The Indiana Department of Natural Resources developed the database to assist in documenting the presence of special species and significant natural areas and to serve as a tool for setting management priorities in areas where special species or habitats exist. The database relies on observations from individuals rather than systematic field surveys by the IDNR. Because of this, it does not document every occurrence of special species or habitat. At the same time, the listing of a species or natural area does not guarantee that the listed species is present or that the listed area is in pristine condition. To assist users, the database includes the date that the species or special habitat was last observed in a specific location.

Appendix C presents the results from the database search for the Pleasant and Riddles Lakes watershed. (For additional reference, Appendix D provides a listing of endangered, threatened, and rare species (ETR) documented in St. Joseph County.) No federally listed endangered, threatened, and rare species are known to exist in the watershed. The state of Indiana uses the following definitions when listing species:

- *Endangered*: Any species whose prospects for survival or recruitment with the state are in immediate jeopardy and are in danger of disappearing from the state. This includes all species classified as endangered by the federal government which occur in Indiana. Plants known to occur currently on five or fewer sites in the state are considered endangered.
- *Threatented*: Any species likely to become endangered within the foreseeable future. This includes all species classified as threatened by the federal government which occur in Indiana. Plants known to occur currently on six to ten sites in the state are considered endangered.
- *Rare*: Plants and insects known to occur currently on from eleven to twenty sites.

The database documents relatively few endangered, threatened, or rare species; high quality natural communities; or natural areas in the Pleasant and Riddles Lakes watershed. The habitat within the watershed supports two state endangered animal species including Kirtland's snake (*Clonophis kirtlandii*) and Blanding's turtle (*Emydiodea blandingii*). Both reptiles were observed relatively recently. Individuals observed Kirtland's snake west of Lakeville near the intersection of Millet Road and Quinn Road in 1987, while the Blanding's turtle was observed in 1999 north of Osborne Road between Maple Road and U.S. Highway 31. The database also indicates that the state rare plant northern bush-honeysuckle (*Lonicera diervilla*) and the state mollusk species of special concern, the swamp lymnaea (*Lymnaea stagnalis*), were also historically located within the watershed. Observation of the rare plant species occurred in 1939 east of Riddles Lake, while the mollusk was observed more recently (1988) within the Heston Ditch floodplain north of Moon Lake.

St. Joseph County supports a variety of endangered, threatened, and rare animals and plants. The listed animals include two mullusks or snails (pointed campeloma and swamp lymnaea), two amphibians (blue-spotted salamander and northern leopard frog), and five reptiles, including the state endangered spotted turtle, Blanding's turtle, Kirtland's snake, copperbelly water snake, and eastern massasauga. One insect (band-winged meadowfly) and fifteen birds, including the state endangered Henslow's sparrow, upland sandpiper, American and least bitterns, black tern, and marsh and sedge wrens and are also listed. Five state endangered mammals, northern river otter, bobcat, Indiana bat (federally endangered), Franklin's ground squirrel, and American badger, have also been identified in the county. More than seventy-five plant species, many of which are hydrophytic (wetland or aquatic species), are also included in the database for St. Joseph County. The county also supports eight high quality communities: wet prairie, acid bog, fen, muck flat, marsh, sedge meadow, forested swamp, and shrub swamp.

3.0 STREAM ASSESSMENT

3.1 Stream Assessment Introduction

To better understand the transport of nutrients and other pollutants to Pleasant and Riddles Lakes from their watershed, this study included an evaluation of the water quality of Heston Ditch, Walters Ditch, and Bunch Ditch, the lakes' main inlet streams. The water quality evaluation consisted of the collection of water samples from the stream. These samples were analyzed for an array of physical and chemical parameters and results of the analysis were compared to historical data, state standards (if available), and other known measures of stream water quality.

The biological communities of Heston Ditch, Walters Ditch, and Bunch Ditch were also assessed to supplement the findings from the physical and chemical parameter analysis. A stream's biological communities (fish, macroinvertebrates, and periphyton communities) tend to reflect the stream's long-term water quality. For example, streams that carry significant sediment loads on a regular basis tend to support few or no stoneflies, since stoneflies are sediment-intolerant organisms. Evaluating the biological community characteristics, such as species diversity and composition, helps understand the stream's water quality over a longer term than can be assessed with the collection of only grab samples.

While a stream's biota serve as a useful means for assessing the stream's water quality, it is important to remember that water quality is not the only factor that shapes a stream's biological community. Habitat quality, energy source, flow regime, and biological pressures (predation, parasitism, competition, etc.) also affect a stream's biological community composition (Karr et al., 1986). For example, a stream fish community dominated by very tolerant fish does not necessarily mean the water quality is very poor. Lack of appropriate spawning habitat or changes in the stream's hydrological regime could plan a larger role in shaping the stream's fish community than water quality in some instances.

To provide a complete assessment of water quality within the inlet streams, the study included the collection of water chemistry and biological (macroinvertebrate) samples. Water quality samples were collected twice, once during base flow or normal conditions and once following a storm event, at the location indicated in Figure 16. The biological community of each of the main streams immediately upstream of its confluence with the lake (Heston Ditch with Pleasant Lake; Bunch Ditch with Pleasant Lake; Walters Ditch with Riddles Lake) was sampled during base flow conditions as required by standard protocol. Sampling occurred in mid-summer to avoid the May and October macroinvertebrate diversity peaks. The in-stream and riparian habitat along all five stream reaches was also evaluated to help in isolating which factors are responsible for shaping the creek's biotic communities. The following section outlines the stream sampling methods in greater detail.

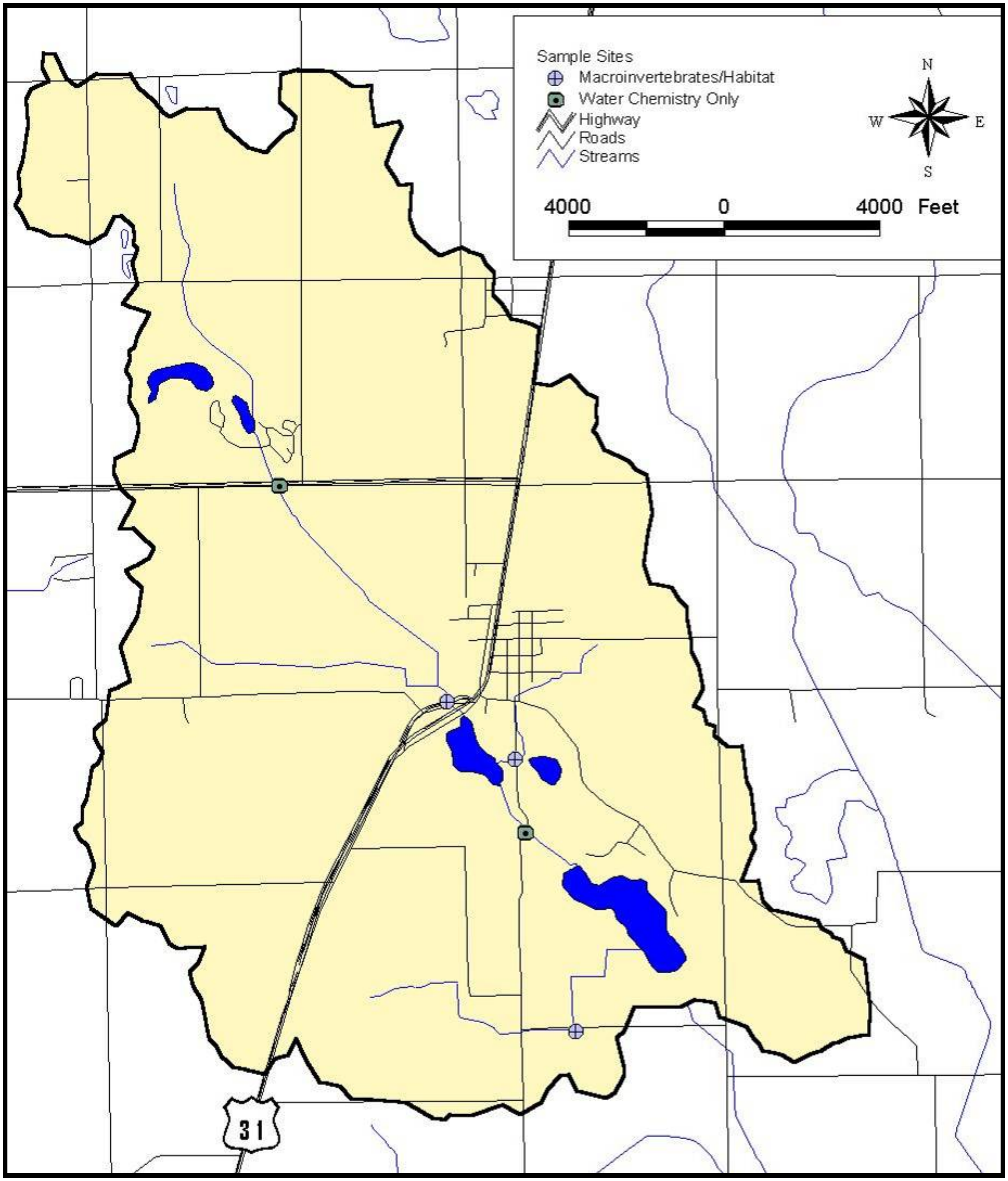

Figure 16. Stream sampling locations.
Source: See Appendix A. Scale: 1"=4,000'.

3.2 Stream Assessment Methods

3.2.1 Water Chemistry

Water samples were collected and analyzed for various parameters from five streams in the Pleasant and Riddles Lakes watershed (Table 12 and Figure 16). The LARE sampling protocol requires assessing the water quality of each designated stream site once during base flow and once during storm flow. This is because water quality characteristics change markedly between these two flow regimes. A storm flow sample will be influenced by runoff from the landscape and usually contains higher concentrations of soil and soil-associated nutrients. A base flow sample represents the 'usual' water characteristics of the stream. Storm flow samples were collected on July 25, 2005, following 1-2 inches (2.5-5 cm) of rain. (The Purdue Agricultural Service field gauge in North Liberty, Indiana reported 1.5 inches of rain on July 25, 2005.) Base flow samples were collected on July 18, 2005 following a period of little precipitation.

Table 12. Location of stream sampling sites.

Site	Stream Name	Sampling Location	Latitude	Longitude
1	Heston Ditch	State Road 4	41° 32.119'	86° 17.690'
2	Heston Ditch	U.S. 31	41° 31.165'	86° 16.668'
3	Bunch Ditch	Linden Road	41° 30.929'	86° 16.349'
4	Heston Ditch	Linden Road	41° 30.934'	86° 16.347'
5	Walters Ditch	Rockstroh Road	41° 29.815'	86° 15.879'

During the current assessment, stream water chemistry samples were analyzed for pH, conductivity, total phosphorus, soluble reactive phosphorus, nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, organic nitrogen, total suspended solids, turbidity, and *E. coli* bacteria. Conductivity, temperature, and dissolved oxygen were measured *in situ* with an YSI Model 85 meter. Stream water velocity was measured using a Marsh-McBirney Flo-Mate current meter. The cross-sectional area of the stream channel was measured and discharge calculated by multiplying water velocity by the cross-sectional area.

All water samples were placed in the appropriate bottle (with preservative if needed) and stored in an ice chest until analysis at Indiana University School of Public and Environmental Affair's (SPEA) laboratory in Bloomington. Soluble reactive phosphorus samples were filtered in the field through a Whatman GF-C filter. The *E. coli* bacteria samples were taken to EIS Analytical Laboratory in South Bend, Indiana for analysis. All sampling techniques and laboratory analytical methods were performed in accordance with procedures in *Standard Methods for the Examination of Water and Wastewater*, 20th Edition (APHA, 1998).

The following is a brief description of the parameters analyzed during the stream sampling efforts:

Temperature. Temperature can determine the form, solubility, and toxicity of a broad range of aqueous compounds. For example, water temperature affects the amount of oxygen dissolved in the water column. Water temperature also governs species composition and activity of aquatic biological communities. Since essentially all aquatic organisms are 'cold-blooded' the temperature of the water regulates their metabolism and ability to survive and reproduce effectively (USEPA, 1976). The Indiana Administrative Code (327 IAC 2-1-6) sets maximum temperature limits to protect aquatic life for Indiana streams according to the time of year. For example, temperatures during the summer months should not exceed 90 °F (32.2 °C).

Dissolved Oxygen (DO). DO is the dissolved gaseous form of oxygen. It is essential for respiration of fish and other aquatic organisms. Fish need at least 3 to 5 mg/L of DO. Coldwater fish such as trout generally require higher concentrations of DO than warmwater fish such as bass or bluegill. The Indiana Administrative Code (IAC) sets minimum DO concentrations at 4 mg/L, but all waters must have a daily average of 5 mg/L. DO enters water by diffusion from the atmosphere and as a byproduct of photosynthesis by algae and plants. Excessive algae growth can over-saturate (greater than 100% saturation) the water with DO. Conversely, dissolved oxygen is consumed by respiration of aquatic organisms, such as fish, and during bacterial decomposition of plant and animal matter.

Conductivity. Conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions: on their total concentration, mobility, and valence (APHA, 1998). During low discharge, conductivity is higher than during high discharge because the water moves more slowly across or through ion containing soils and substrates during base flow. Carbonates and other charged particles (ions) dissolve into the slow-moving water, thereby increasing conductivity measurements.

Rather than setting a conductivity standard, the IAC sets a standard for dissolved solids (750 mg/L). Multiplying a dissolved solids concentration by a conversion factor of 0.55 to 0.75 μmhos per mg/L of dissolved solids roughly converts a dissolved solids concentration to specific conductance (Allan, 1995). Thus, converting the IAC dissolved solids concentration standard to specific conductance by multiplying 750 mg/L by 0.55 to 0.75 μmhos per mg/L yields a specific conductance range of approximately 1000 to 1360 μmhos. This report presents conductivity measurements at each site in μmhos.

pH. The pH of water describes the concentration of acidic ions (specifically H+) present in water. Water's pH determines the form, solubility, and toxicity of a wide range of other aqueous compounds. The IAC establishes a range of 6 to 9 pH units for the protection of aquatic life. pH concentrations in excess of 9 are considered acceptable when the concentration occurs as daily fluctuations associated with photosynthetic activity.

Nutrients. Scientists measure nutrients to predict the amount of algae growth and/or rooted plant (macrophyte) growth that is possible in a lake or stream. Algae and rooted plants are a natural and necessary part of aquatic ecosystems. Both will always occur in a healthy lake or stream. Complete elimination of algae and/or rooted plants is neither desirable nor even possible and should, therefore, never be the goal in managing a lake or stream. Algae and rooted plant growth can, however, reach nuisance levels and interfere with the aesthetic and recreational uses of a lake or stream. Scientists commonly measure nutrient concentrations in aquatic ecosystem evaluations to determine the potential for such nuisance growth.

Nutrients themselves, as well as the primary producers (algae and plants) they feed, can also affect the composition of secondary producer communities such as macroinvertebrates and fish. Changes in secondary producer communities can, in turn, impact the way chemical constituents in the water are processed. This is an additional reason for examining nutrient levels in an aquatic ecosystem.

Phosphorus and nitrogen have several forms in water. The two common phosphorus forms are **soluble reactive phosphorus (SRP)** and **total phosphorus (TP)**. SRP is the dissolved form of phosphorus. It is the form that is "usable" by algae. Algae cannot directly digest and use particulate phosphorus. Total phosphorus is a measure of both dissolved and particulate forms of phosphorus. The most commonly measured nitrogen forms are **nitrate-nitrogen (NO_3)**, **ammonium-nitrogen (NH_4^+)**, and **total Kjeldahl nitrogen (TKN)**. Nitrate is a dissolved form of nitrogen that is commonly found in the upper layers of a lake or anywhere that oxygen is readily available. Because oxygen should be readily available in stream systems, nitrate-nitrogen is often the dominant dissolved form of nitrogen in stream systems. In contrast, ammonium-nitrogen is generally found where oxygen is lacking. Ammonium is a byproduct of decomposition generated by bacteria as they decompose organic material. Like SRP, ammonium is a dissolved form of nitrogen and the one utilized by algae for growth. The TKN measurement parallels the TP measurement to some extent. TKN is a measure of the **total organic nitrogen** (particulate) and ammonium-nitrogen in the water sample.

While the United States Environmental Protection Agency (USEPA) has established some nutrient standards for drinking water safety, it has not established similar nutrient standards for protecting the biological integrity of a stream. (The USEPA, in conjunction with the States, is currently working on developing these standards.) The USEPA has issued recommendations for numeric nutrient criteria for streams (USEPA, 2000b). While these are not part of the Indiana Administrative Code, they serve as potential target conditions for which watershed managers might aim. The Ohio EPA has also made recommendations for numeric nutrient criteria in streams based on research on Ohio streams (Ohio EPA, 1999). These, too, serve as potential target conditions for those who manage Indiana streams. Other researchers have suggested thresholds for several nutrients in aquatic ecosystems as well (Dodd et al., 1998). Lastly, the Indiana Administrative Code (IAC) requires that all waters of the state have a nitrate concentration of less than 10 mg/L, which is the drinking water standard for the state.

Researchers have recommended various thresholds and criteria for nutrients in streams. The USEPA's recommended targets for nutrient levels in streams are fairly low. The agency recommends a target total phosphorus concentration of 0.076 mg/L in streams (USEPA, 2000b). Dodd et al. (1998) suggest the dividing line between moderately (mesotrophic) and highly (eutrophic) productive streams is a total phosphorus concentration of 0.07 mg/L. The Ohio EPA recommended a total phosphorus concentration of 0.08 mg/L in headwater streams to protect the streams' aquatic biotic integrity (Ohio EPA, 1999). (This criterion is for streams classified as Warmwater Habitat, or WWH, meaning the stream is capable of supporting a healthy, diverse warmwater fauna. Streams that cannot support a healthy, diverse community of warmwater fauna due to "irretrievable, extensive, man-induced modification" are classified as Modified Warmwater Habitat (MWH) streams and have a different criterion.) While the entire length of streams within the Pleasant and Riddles Lakes watershed may not fit the WWH definition, 0.08 to 0.1 mg/L is a good goal for the streams.

The USEPA sets aggressive nitrogen criteria recommendations for streams compared to the Ohio EPA. The USEPA's recommended criteria for nitrate-nitrogen and total Kjeldahl nitrogen concentrations for streams in Aggregate Nutrient Ecoregion VII are 0.633 mg/L and 0.591 mg/L, respectively (USEPA, 2000b). In contrast, the Ohio EPA suggests using nitrate-nitrogen criteria of 1.0 mg/L in WWH wadeable and headwater streams and MWH headwater streams to protect aquatic life. Dodd et al. (1998) suggests the dividing line between moderately and highly productive streams using nitrate-nitrogen concentrations is approximately 1.5 mg/L.

It is important to remember that none of the threshold or recommended concentrations listed above are state standards for water quality. They are presented here to provide a frame of reference for the concentrations found in streams in the Pleasant and Riddles Lakes watershed. The IAC sets only nitrate-nitrogen and ammonia-nitrogen standards for waterbodies in Indiana. The Indiana Administrative Code requires that all waters of the state have a nitrate-nitrogen concentration of less than 10 mg/L, which is the drinking water standard for the state. The IAC standard for ammonia-nitrogen depends upon the water's pH and temperature, since both can affect ammonia-nitrogen's toxicity. The draft 2006 303(d) list of impaired waterbodies listing criteria indicates that the IDEM will include waterbodies with total phosphorus concentrations greater than 0.3 mg/L on subsequent lists of impaired waterbodies (Indiana Register, 2005).

Turbidity. Turbidity (measured in Nephelometric Turbidity Units) is a measure of particles suspended in the water itself. It is generally related to suspended and colloidal matter such as clay, silt, finely divided organic and inorganic matter, plankton, and other microscopic organisms. According to the Hoosier Riverwatch, the average turbidity of an Indiana stream is 11 NTU with a typical range of 4.5 to 17.5 NTU (Crighton and Hosier, 2004). Turbidity measurements >20 NTU have been found to cause undesirable changes in aquatic life (Walker, 1978). As part of their effort to make numeric nutrient criteria recommendations, the USEPA set 9.9 NTUs as a target for turbidity in stream ecosystems (USEPA, 2000b).

Total Suspended Solids (TSS). A TSS measurement quantifies all particles suspended and dissolved in water. Closely related to turbidity, this parameter quantifies sediment particles and other solid compounds typically found in water. In general, the concentration of suspended solids is greater in streams during high flow events due to increased overland flow. The increased overland flow erodes and carries more soil and other particulates to the stream. The sediment in water originates from many sources, but a large portion of sediment entering streams comes from active construction sites or other disturbed areas such as unvegetated stream banks and poorly managed farm fields.

Suspended solids impact streams and lakes in a variety of ways. When suspended in the water column, solids can clog the gills of fish and invertebrates. As the sediment settles to the creek or lake bottom, it covers spawning and resting habitat for aquatic fauna, reducing the animals' reproductive success. Suspended sediments also impair the aesthetic and recreational value of a waterbody. Few people are enthusiastic about having a picnic near a muddy creek or lake. Pollutants attached to sediment also degrade water quality. In general, TSS concentrations greater than 80 mg/L have been found to be deleterious to aquatic life (Waters, 1995).

***E. coli* Bacteria.** *E. coli* is one member of a group of bacteria that comprise the fecal coliform bacteria and is used as an indicator organism to identify the potential for the presence of pathogenic organisms in a water sample. Pathogenic organisms can present a threat to human health by causing a variety of serious diseases, including infectious hepatitis, typhoid, gastroenteritis, and other gastrointestinal illnesses. *E. coli* can come from the feces of any warm-blooded animal. Wildlife, livestock, and/or domestic animal defecation, manure fertilizers, previously contaminated sediments, and failing or improperly sited septic systems are common sources of the bacteria. The IAC sets the maximum concentration of *E. coli* at 235 colonies/100 mL in any one sample within a 30-day period or a geometric mean of 125 colonies per 100 mL for five samples collected in any 30-day period.

3.2.2 Macroinvertebrates

Aquatic macroinvertebrates are important indicators of environmental change. Numerous studies have shown that different macroinvertebrate orders and families react differently to pollution sources. Additionally, aquatic biota integrate cumulative effects of sediment and nutrient pollution (Ohio EPA, 1995). Thus, a stream's insect community composition provides a long term reflection of the stream's water quality.

To help evaluate the water quality flowing into Pleasant and Riddles Lakes, macroinvertebrates were collected during base flow conditions on July 19, 2005 from Pleasant and Riddles Lakes watershed streams using the multihabitat approach detailed in the USEPA Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers, 2nd ed. (Barbour et al., 1999). Organisms were identified to the family level. The family-level approach was used: 1) to collect data comparable to that collected by IDEM in the state; 2) because it allows for increased organism identification accuracy; and 3) because several studies support the adequacy of family-level analysis (Furse et al., 1984; Ferraro and Cole, 1995; Marchant, 1995; Bowman and Bailey, 1997; Waite et al., 2000).

The benthic community in the streams was evaluated using IDEM's macroinvertebrate Index of Biotic Integrity (mIBI). The mIBI is a multi-metric index that combines several aspects of the benthic community composition. As such, it is designed to provide a complete assessment of a creek's biological integrity. Karr and Dudley (1981) define biological integrity as "the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to the best natural habitats within a region". It is likely that this definition of biological integrity is what IDEM means by biological integrity as well. The mIBI consists of ten metrics (Table 13) which measure the species richness, evenness, composition, and density of the benthic community at a given site. The metrics include family-level HBI (Hilsenhoff's FBI or family level biotic index; Hilsenhoff, 1988), number of taxa, number of individuals, percent dominant taxa, EPT Index, EPT count, EPT count to total number of individuals, EPT count to Chironomid count, Chironomid count, and total number of individuals to number of squares sorted. (EPT stands for the *Ephemeroptera, Plecoptera*, and *Trichoptera* orders.) A classification score of 0, 2, 4, 6, or 8 is assigned to specific ranges for metric values. For example, if the benthic community being assessed supports nine different families, that community would receive a classification score of 2 for the "Number of Taxa" metric. The mIBI is calculated by averaging the classification scores for the ten metrics. mIBI scores of 0-2 indicate the sampling site is severely impaired; scores of 2-4 indicate the site is moderately impaired; scores of 4-6 indicate the site is slightly impaired; and scores of 6-8 indicate that the site is non-impaired.

IDEM developed the classification criteria based on five years of wadeable riffle-pool data collected in Indiana. Because the values for some of the metrics can vary depending upon the collection and subsampling methodologies used to survey a stream, it is important to adhere to the collection and subsampling protocol IDEM used when it developed the mIBI. Since the multihabitat approach detailed in the USEPA Rapid Bioassessment Protocols for Use in Wadeable Streams and Rivers, 2nd ed. (Barbour et al., 1999) was utilized in this survey to ensure adequate representation of all macroinvertebrate taxa, the mIBI at each site was calculated without the protocol dependent metrics of the mIBI (number of individuals and number of individuals to number of squares sorted).

(Protocol dependent methods were defined by Steve Newhouse, IDEM, in personal correspondence.) Eliminating the protocol dependent metrics allows the mIBI scores at sites surveyed using different survey protocols to be compared to mIBI scores at sites sampled using the IDEM recommended protocol.

Table 13. Benthic macroinvertebrate scoring criteria used by IDEM in the evaluation of pool-riffle streams in Indiana.

	SCORING CRITERIA FOR THE FAMILY LEVEL MACROINVERTEBRATE INDEX OF BIOTIC INTEGRITY (mIBI) USING PENTASECTION AND CENTRAL TENDENCY ON THE LOGARITHMIC TRANSFORMED DATA DISTRIBUTIONS OF THE 1990-1995 RIFFLE KICK SAMPLES				
	CLASSIFICATION SCORE				
	0	2	4	6	8
Family Level HBI	≥5.63	5.62- 5.06	5.05-4.55	4.54-4.09	≤4.08
Number of taxa	≤7	8-10	11-14	15-17	≥18
Number of individuals	≤79	129-80	212-130	349-213	≥350
Percent dominant taxa	≥61.6	61.5-43.9	43.8-31.2	31.1-22.2	<22.1
EPT index	≤2	3	4-5	6-7	≥8
EPT count	≤19	20-42	43-91	92-194	≥195
EPT count to total number of individuals	≤0.13	0.14-0.29	0.30-0.46	0.47-0.68	≥0.69
EPT count to chironomid count	≤0.88	0.89-2.55	2.56-5.70	5.71-11.65	≥11.66
Chironomid count	≥147	146-55	54-20	19-7	≤6
Total number of individuals to number of squares sorted	≤29	30-71	72-171	172-409	≥410

Where: 0-2 = Severely Impaired, 2-4 = Moderately Impaired, 4-6 = Slightly Impaired, 6-8 = Non-impaired

Although the Indiana Administrative Code does not include mIBI scores as numeric criteria for establishing whether streams meet their aquatic life use designation, the IDEM hints that it may be using mIBI scores to make this determination. (Under state law, all waters of the state, except for those noted as Limited Use in the Indiana Administrative Code, must be capable of supporting recreational and aquatic life uses.) In the 2006 draft 303(d) listing methodology, the IDEM suggests that those waterbodies with mIBI scores less than 1.4 when using the multi-habitat approach are considered non-supporting for aquatic life use. Similarly, waterbodies with mIBI scores greater than 1.4 when assessed using the multi-habitat approach are considered fully supporting for aquatic life use (Indiana Register, 2005). Under federal law, waters that do not meet their designated uses must be placed on the 303(d) list and remediation/restoration plans (Total Maximum Daily Load plans) must be developed for these waters.

3.2.3 Habitat

The physical habitat at the sampling sites for each of the streams was evaluated using the Qualitative Habitat Evaluation Index (QHEI) The Ohio EPA developed the QHEI for streams and rivers in Ohio (Rankin 1989, 1995). The QHEI is a physical habitat index designed to provide an empirical, quantified evaluation of the general lotic macrohabitat (Ohio EPA, 1989). While the Ohio EPA originally developed the QHEI to evaluate ***fish*** habitat in streams, IDEM and other agencies routinely utilize the QHEI as a measure of general "habitat" health. The QHEI is composed of six metrics including substrate composition, in-stream cover, channel morphology, riparian zone and bank erosion, pool/glide and riffle-run quality, and map gradient. Each metric is scored individually then summed to provide the total QHEI score. The QHEI score generally ranges from 20 to 100.

Substrate type(s) and quality are important factors of habitat quality and the QHEI score is partially based on these characteristics. Sites that have greater substrate diversity receive higher scores as they can provide greater habitat diversity for benthic organisms. The quality of substrate refers to the embeddedness of the benthic zone. Because the rocks (gravel, cobble, boulder) that comprise a stream's substrate do not fit together perfectly like pieces in a jigsaw puzzle, small pores and crevices exist between the rock in the stream's substrate. Many stream organisms can colonize these pores and crevices, or microhabitats. In streams that carry high silt loads, the pores and crevices between rock substrate become clogged over time. This clogging, or "embedding", of the stream's substrate eliminates habitat for the stream's biota. Thus, sites with heavy embeddedness and siltation receive lower QHEI scores for the substrate metric.

In-stream cover, another metric of the QHEI, refers to the type(s) and quantity of habitat provided within the stream itself. Examples of in-stream cover include woody logs and debris, aquatic and overhanging vegetation, and root wads extending from the stream banks. The channel morphology metric evaluates the stream's physical development with respect to habitat diversity. Pool and riffle development within the stream reach, the channel sinuosity, and other factors that represent the stability and direct modification of the site comprise this metric score.

A stream's buffer, which includes the riparian zone and floodplain zone, is a vital functional component of riverine ecosystems. It is instrumental in the detention, removal, and assimilation of nutrients. Riparian zones govern the quality of goods and services provided by riverine ecosystems (Ohio EPA, 1999). Riparian zone (the area immediately adjacent to the stream), floodplain zone (the area beyond the riparian zone that may influence the stream though runoff), and bank erosion were examined at each site to evaluate the quality of the buffer zone of the stream, the land use within the floodplain that affects inputs to the waterway, and the extent of erosion in the stream, which can reflect insufficient vegetative stabilization of the stream banks. For the purposes of the QHEI, a riparian zone consists only of forest, shrub, swamp, or woody old field vegetation. Typically, weedy, herbaceous vegetation has higher runoff potential than woody components and does not represent an acceptable riparian zone type for the QHEI (Ohio EPA, 1989). Streams with grass or other herbaceous vegetation growing in the riparian zone receive low QHEI scores for this metric.

Metric 5 of the QHEI evaluates the quality of pool/glide and riffle/run habitats in the stream. These zones in a stream, when present, provide diverse habitat and, in turn, can increase habitat quality. The depth of pools within a reach and the stability of riffle substrate are some factors that affect the QHEI score in this metric.

The final QHEI metric evaluates the topographic gradient in a stream reach. This is calculated using topographic data. The score for this metric is based on the premise that both very low and very high gradient streams will have negative effects on habitat quality. Moderate gradient streams receive the highest score, 10, for this metric. The gradient ranges for scoring take into account the varying influence of gradient with stream size.

The QHEI evaluates the characteristics of a stream segment, as opposed to the characteristics of a single sampling site. As such, individual sites may have poorer physical habitat due to a localized disturbance yet still support aquatic communities closely resembling those sampled at adjacent sites with better habitat, provided water quality conditions are similar. QHEI scores from hundreds of stream segments in Ohio have indicated that values greater than 60 are *generally* conducive to the existence of warmwater faunas. Scores greater than 75 typify habitat conditions that have the ability to support exceptional warmwater faunas (Ohio EPA, 1999). IDEM indicates that QHEI scores above 64 suggest the habitat is capable of supporting a balanced warmwater community; scores between 51 and 64 are only partially supportive of a stream's aquatic life use designation (IDEM, 2000).

3.3 Stream Assessment Results and Discussion

3.3.1 Water Chemistry

Physical Concentrations and Characteristics

Physical parameter results measured during base and storm flow sampling of the Pleasant and Riddles Lakes watershed streams are presented in Table 14. Stream discharges measured during base and storm flow conditions are shown in Figure 17. Stream cross-sections, which were determined while measuring discharge, are shown in Figure 18. The cross sections indicate that all of the stream sites possess extremely straight stream banks as is typical of drainage ditches that have not recovered from channelization and dredging.

Table 14. Physical characteristics of the Pleasant and Riddles Lakes watershed streams on July 19, 2005 (base flow) and July 25, 2005 (storm flow).

Site	Date	Timing	Flow (cfs)	Temp (°C)	DO (mg/L)	% Sat.	Cond (μmhos)	pH	Alk (mg/L)	TSS (mg/L)	Turb (NTU)
1	7/19/05	Base	0.03	20.8	0.0	0.5	652	7.3	251	55.4	--
	7/25/05	Storm	0.15	22.3	1.8	21.2	557	7.1	--	18.7	6.0
2	7/19/05	Base	0.38	23.2	0.0	0.4	348	7.4	100	12.1	--
	7/25/05	Storm	1.24	24.8	0.7	7.8	305	7.1	--	18.0	7.0
3	7/19/05	Base	0.01	23.9	0.0	0.4	537	7.5	121	36.3	--
	7/25/05	Storm	1.55	22.1	3.3	37.2	329	7.2	--	1,131.8	35.5
4	7/19/05	Base	--	28.8	3.1	43.6	435	7.5	135	40.4	--
	7/25/05	Storm	2.72	26.6	1.1	14.2	394	7.2	--	13.7	2.7
5	7/19/05	Base	0.02	23.4	6.3	76.3	760	8.1	269	18.0	--
	7/25/05	Storm	0.49	21.0	4.2	46.5	718	7.3	--	21.3	11.0

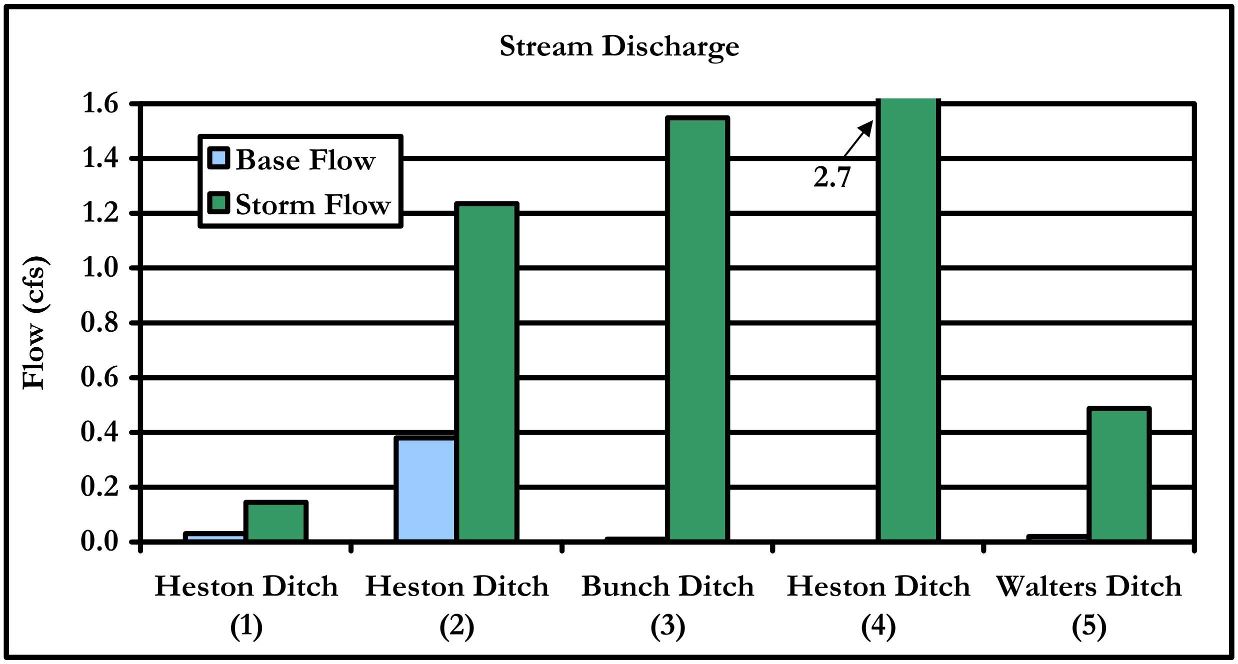

Figure 17. Discharge measurements during base flow and storm flow sampling of Pleasant and Riddles Lakes watershed streams.

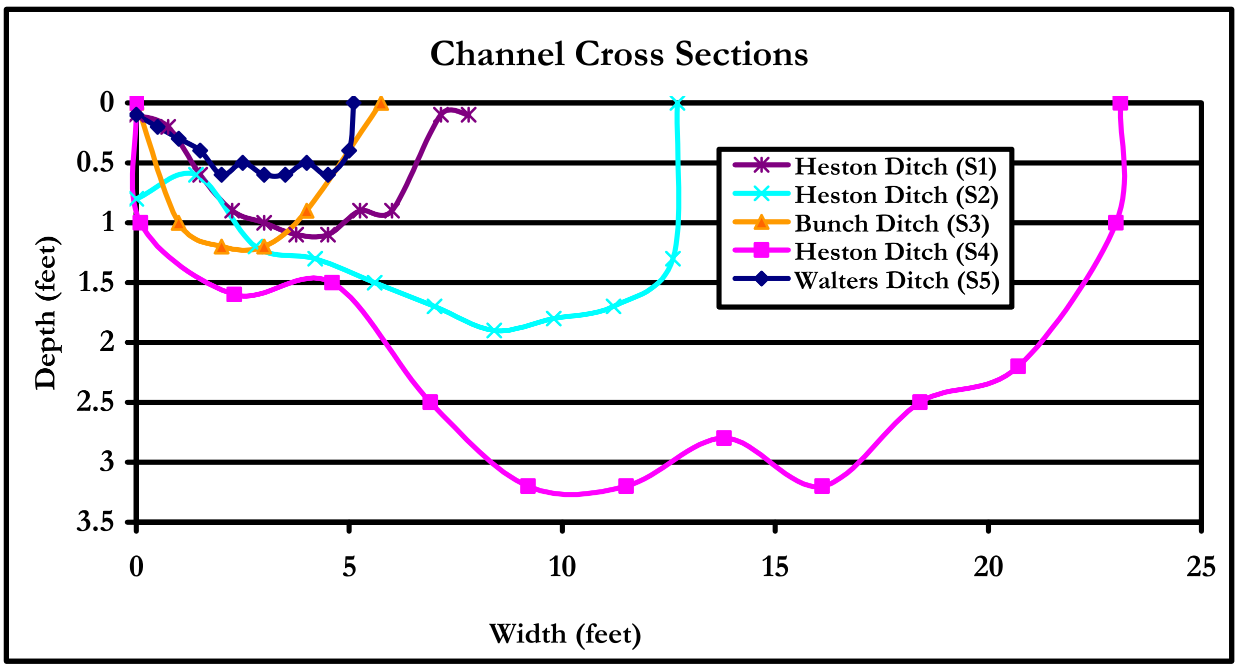

Figure 18. Physical dimensions at the sampling locations of Pleasant and Riddles Lakes watershed streams.

Alkalinity, pH, and conductivity values were within normal ranges for Indiana streams. Alkalinity concentrations were typical of well-buffered streams, suggesting the presence of carbonates and other alkalinity-producing materials in the watershed's bedrock. Alkalinity ranged from 100 mg/L in the Heston Ditch upstream of Pleasant Lake (Site 2) at base flow to 269 mg/L in Walters Ditch (Site 5) at base flow. The watershed streams' pH values were somewhat alkaline, ranging from 6.1 in

Heston Ditch upstream of Pleasant Lake (Site 2) at storm flow to 8.1 in Walters Ditch (Site 5) during base flow. All of the pH values were within the range that is appropriate for supporting aquatic life. Conductivity values ranged from 348 μmhos in Heston Ditch upstream of Pleasant Lake (Site 2) to 760 μmhos in Walters Ditch (Site 5) during base flow and from 305 μmhos in Heston Ditch upstream of Pleasant Lake (Site 2) to 707 μmhos in Walters Ditch (Site 5) during storm flow. None of the conductivity values exceeded the Indiana state water quality standard.

Water temperatures in the Pleasant and Riddles Lakes watershed streams varied slightly between storm and base flow sampling events. Generally, stream temperatures during storm flow conditions were lower than stream temperatures measured during base flow conditions. Water temperatures during the storm flow ranged from 21.0 °C (69.8 °F) in Walters Ditch (Site 5) to 26.6 °C (79.9 °F) in Heston Ditch between Pleasant and Riddles Lakes (Site 3). Greater variation was observed during base flow when stream temperatures ranged from 20.8 °C (69.4 °F) in Heston Ditch headwaters (Site 1) to 28.8 °C (83.8 °F) in Heston Ditch between Pleasant and Riddles Lakes (Site 4). None of the observed water temperatures exceeded the Indiana Administrative Code standard for the protection of aquatic life.

Base flow dissolved oxygen concentrations in the Pleasant and Riddles Lakes watershed streams ranged from 0.02 mg/L in the Heston Ditch headwaters (Site 1) to 6.3 mg/L in the Walters Ditch (Site 5). During storm flow, dissolved oxygen concentrations ranged from 0.7 mg/L in Heston Ditch upstream of Pleasant Lake (Site 2) to 4.2 in Walters Ditch (Site 5). All of the streams except Walters Ditch (Site 5) during base flow possessed dissolved oxygen levels below the minimum IAC level of 5 mg/L set to protect aquatic life. Dissolved oxygen saturation levels at base flow were also relatively low for Indiana streams. DO saturation refers to the amount of oxygen dissolved in water compared to the total amount possible when equilibrium between the stream water and the atmosphere is maximized. When a stream is less than 100% saturated with oxygen, decomposition processes within the stream may be consuming oxygen more quickly than it can be replaced and/or flow in the stream is not turbulent enough to entrain sufficient oxygen. In the case of the Pleasant and Riddles Lakes watershed streams, slow or even negligible flow in the streams for much of the summer limited the amount of dissolved oxygen that could be entrained in the stream. This lack of flow created conditions where dissolved oxygen was being consumed much faster than it could be replaced by oxygen from the atmosphere.

Total suspended solids concentrations in the Pleasant and Riddles Lakes watershed streams ranged from 12.1 mg/L in Heston Ditch upstream of Pleasant Lake (Site 2) to 55.4 mg/L in Heston Ditch headwaters (Site 1) during base flow and from 13.7 mg/L in Heston Ditch between the lakes (Site 4) to 1131.8 mg/L in Bunch Ditch (Site 3) during storm flow (Figure 19). Total suspended solids concentrations are higher than is typical for Indiana streams. This is likely due to the algae and duckweed densities present within the streams. Total suspended solids concentrations usually increase with increased stream flow because of in-stream scouring and inputs from overland flow from surrounding lands. This relationship occurred in three of the five watershed streams: Heston Ditch upstream of Pleasant Lake (Site 2), Bunch Ditch (Site 3), and Walters Ditch (Site 5). The storm flow TSS concentration measured in Bunch Ditch (Site 3) is nearly 30 times higher than the concentration present during base flow. Local land use activities could result in isolated increases in erosion during base flow measurement, leading to increased total suspended solids concentration. Only the concentration in Bunch Ditch (Site 3) during storm flow exceeded 80 mg/L, the threshold at which Waters (1995) found to be deleterious to aquatic life.

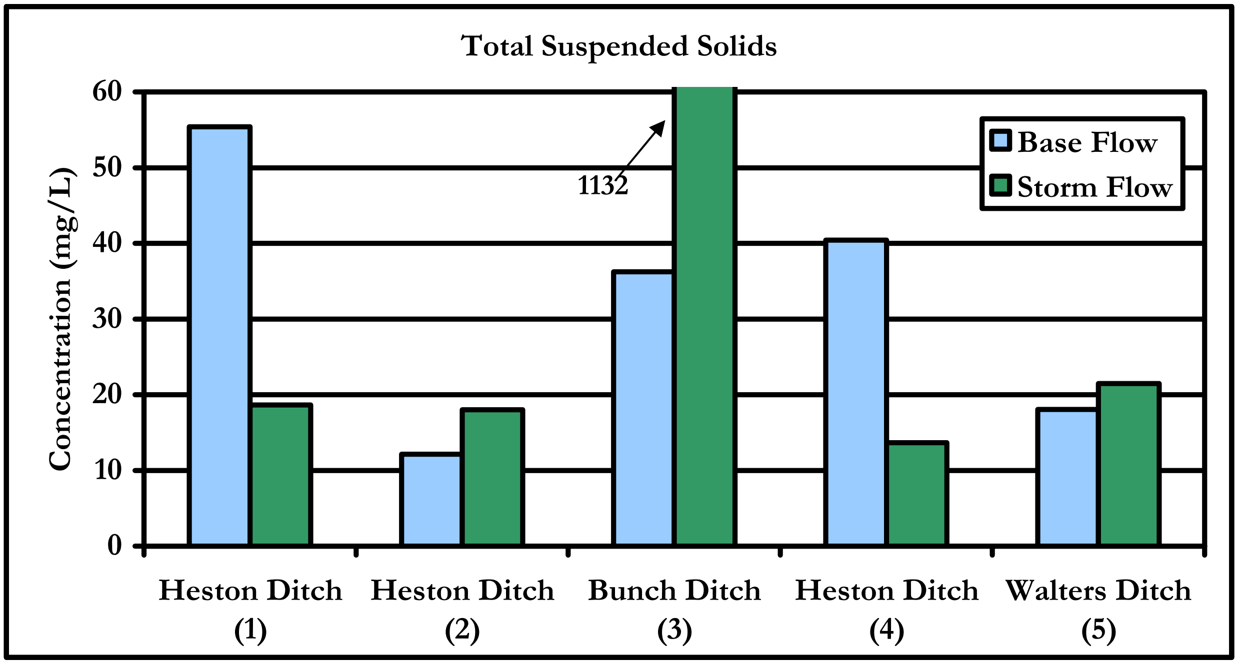

Figure 19. Total suspended solids measurements in Pleasant and Riddles Lakes watershed streams as sampled July 19, 2005 (base flow) and July 25, 2005 (storm flow).

Turbidity concentrations in the Pleasant and Riddles Lakes watershed streams were generally low with the exception of Bunch Ditch (Site 3) during the storm flow event. During storm flow, turbidity concentrations ranged from 2.7 NTU in the Heston Ditch between Pleasant and Riddles lakes (Site 4) to 35.5 NTU in Bunch Ditch (Site 3). As with the total suspended solids concentrations, turbidity concentrations in streams are expected to be higher during storm flow conditions. Storms tend to wash soil and other particulates from the landscape into streams, resulting in higher turbidity concentrations. Only Bunch Ditch (Site 3) during storm flow possessed a turbidity concentration above the USEPA recommended target of 9.9 NTU (USEPA, 2000a). Additionally, this same sample site contained a turbidity concentration more than 1.5 times higher than the level recommended by Walker (1978) for protecting aquatic biota.

Chemical and Bacterial Characteristics

The chemical and bacterial characteristics of the Pleasant and Riddles Lakes watershed streams during base and storm flow conditions are shown in Table 15. In a recent study of 85 relatively undeveloped basins across the United States, the USGS reported the following median concentrations: ammonia (0.020 mg/L), nitrate (0.087 mg/L), total nitrogen (0.26 mg/L), soluble reactive phosphorus (0.010 mg/L), and total phosphorus (0.022 mg/L) (Clark et al., 2000). Nutrient concentrations in the Pleasant and Riddles Lakes streams all exceeded these median concentrations, some parameters by two orders of magnitude.

Table 15. Chemical and bacterial characteristics of the Pleasant and Riddles Lakes watershed streams on July 19, 2005 (base flow) and July 25, 2005 (storm flow).

Site	Date	Timing	Nitrate (mg/L)	Ammonia (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	*E. coli* (#/100mL)
1	7/19/05	Base	0.013*	0.870	4.037	0.086	0.442	990
	7/25/05	Storm	0.106	1.221	3.501	0.155	0.407	7,900
2	7/19/05	Base	0.026	0.103	1.656	0.029	0.156	130
	7/25/05	Storm	0.148	0.185	1.859	0.072	0.350	2,900
3	7/19/05	Base	0.092	0.663	2.646	0.349	0.786	3,900
	7/25/05	Storm	1.567	1.075	3.764	0.204	0.230	800,000
4	7/19/05	Base	0.013*	0.027	1.691	0.014	0.170	450
	7/25/05	Storm	0.015	0.045	1.785	0.026	0.179	800
5	7/19/05	Base	0.930	0.122	0.607	0.089	0.192	3,600
	7/25/05	Storm	9.776	0.746	1.640	0.306	0.534	26,000

*Method detection level.

Nitrate-nitrogen concentrations in the Pleasant and Riddles Lakes watershed streams were relatively low for Indiana streams during base flow; however, concentrations in Walters and Bunch ditches were elevated during storm flow (Figure 20). During base flow, nitrate-nitrogen concentrations ranged from below the detection limit (0.013 mg/L) in Heston Ditch headwaters (Site 1) and Heston Ditch between Pleasant and Riddles Lakes (Site 4) to a high of 0.93 mg/L in the Walters Ditch (Site 5). During storm flow, nitrate-nitrogen concentrations ranged from 0.015 mg/L in Heston Ditch between Pleasant and Riddles Lakes (Site 4) to a high of 9.776 mg/L in Walters Ditch (Site 5). Only Bunch Ditch (Site 3) during storm flow and Walters Ditch (Site 5) during base and storm flows exceeded the USEPA recommended criteria (0.633 mg/L). Nitrate-nitrogen concentrations in the Bunch Ditch (Site 3) and Walters Ditch (Site 5) during storm flow conditions also exceeded the Ohio EPA criteria (1 mg/L) recommended to support aquatic biota in warmwater habitat. These same sample sites possessed nitrate-nitrogen concentrations in excess of the productive to highly-productive threshold (1.5 mg/L) identified by Dodd et al. (1998). Walters Ditch during storm flow exhibited nitrate-nitrogen concentrations above the level recommended by the Ohio EPA (1.6 mg/L) for the protection of aquatic biota in a modified warmwater habitat stream. Additionally, Walters Ditch possessed nitrate-nitrogen concentrations of 3-4 mg/L, the threshold at which Ohio EPA found to definitively impair biotic communities (Ohio EPA, 1999). None of the watershed streams possessed nitrate-nitrogen concentrations that violated the Indiana state water quality standard (10 mg/L).

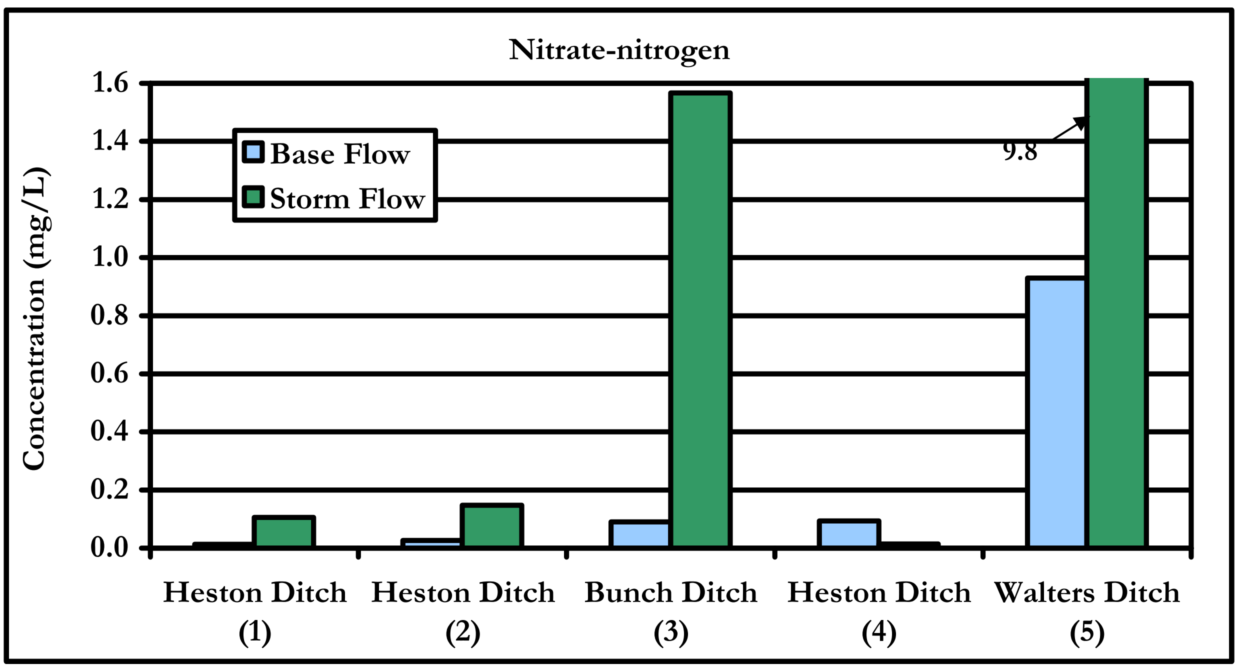

Figure 20. Nitrate-nitrogen concentrations in Pleasant and Riddles Lakes watershed streams as sampled July 19, 2005 (base flow) and July 25, 2005 (storm flow). Detection limit is 0.013 mg/L.

Ammonia-nitrogen concentrations ranged from 0.027 mg/L in Heston Ditch between Pleasant and Riddles Lakes (Site 4) during base flow to 1.221 mg/L in Heston Ditch headwaters (Site 1) during storm flow (Figure 21). Relatively high ammonia-nitrogen concentrations were observed in Heston Ditch headwaters (Site 1) and Walters Ditch (Site 5) during base and storm flow and in Bunch Ditch (Site 3) during storm flow. Ammonia is a by-product of decomposition and therefore streams with high levels of organic material, like Heston Ditch, are expected to have higher ammonia concentrations. All three of these streams possessed high total phosphorus concentrations during the same sampling event that they registered the high ammonia concentrations. High total phosphorus concentrations are indicative of high levels of organic matter. Similarly, Heston Ditch headwaters (Site 1) and Bunch Ditch (Site 3) possessed high total organic nitrogen (total Kjeldahl nitrogen minus ammonia) levels during both base flow and storm flow conditions, suggesting the presence of organic matter. Heston Ditch's substrate is composed largely of muck and silty organic matter, so the high ammonia concentration in that stream is not surprising. Additionally, the sluggish nature of Heston Ditch compounds the ammonia problem. Small, natural streams are typically well-oxygenated because of the turbulent flow. In well-oxygenated streams, ammonia is usually oxidized to nitrate. However, oxygen does not readily diffuse into the slow flowing Heston Ditch, and this chemical reaction likely does not occur as readily there. Dissolved oxygen concentrations were low in all streams in the Pleasant and Riddles Lakes watershed streams especially Heston Ditch during both base and storm flow.

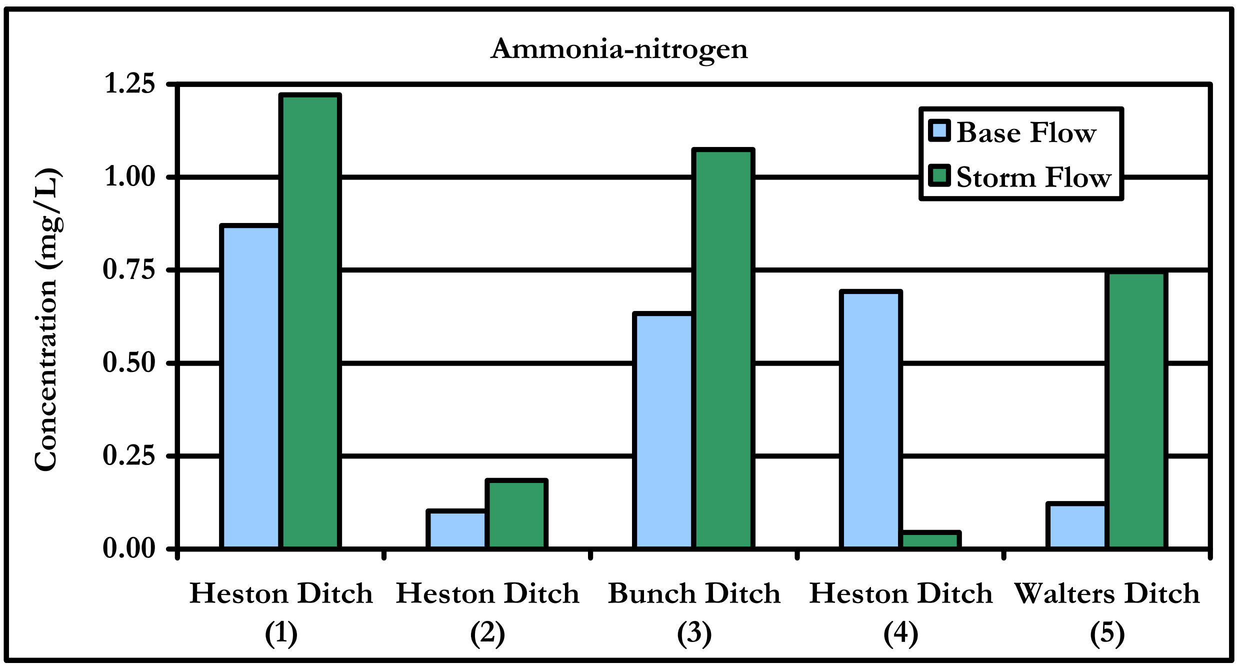

Figure 21. Ammonia-nitrogen concentrations in Pleasant and Riddles Lakes watershed streams as sampled July 19, 2005 (base flow) and July 25, 2005 (storm flow).

Total Kjeldahl nitrogen levels in the Pleasant and Riddles Lakes watershed streams were relatively high for northern Indiana streams. TKN concentrations ranged from 0.607 mg/L in Walters Ditch (Site 5) to 4.037 mg/L in Heston Ditch headwaters (Site 1) during base flow and from 1.640 mg/L in Walters Ditch (Site 5) to 3.764 mg/L in Bunch Ditch (Site 3) during storm flow (Figure 22). Relatively high TKN concentrations were also observed in Bunch Ditch (Site 3) at base flow and Heston Ditch headwaters (Site 1) under storm flow conditions. Typically, storm flow concentrations of TKN exceed base flow concentrations since runoff liberates significant organic material stored within the stream and in riparian areas adjacent to the stream. This relationship existed at all sampling sites except the Heston Ditch headwaters (Site 1) stream. The Heston Ditch headwaters stream exhibited relatively similar base flow and storm flow TKN concentrations. This may be due to the minor change in stream flow between base and storm flow conditions and the high level of organic material in the Heston Ditch headwaters. All of the streams possessed TKN concentrations greater than the target concentration of 0.591 mg/L recommended by the USEPA (2000a).

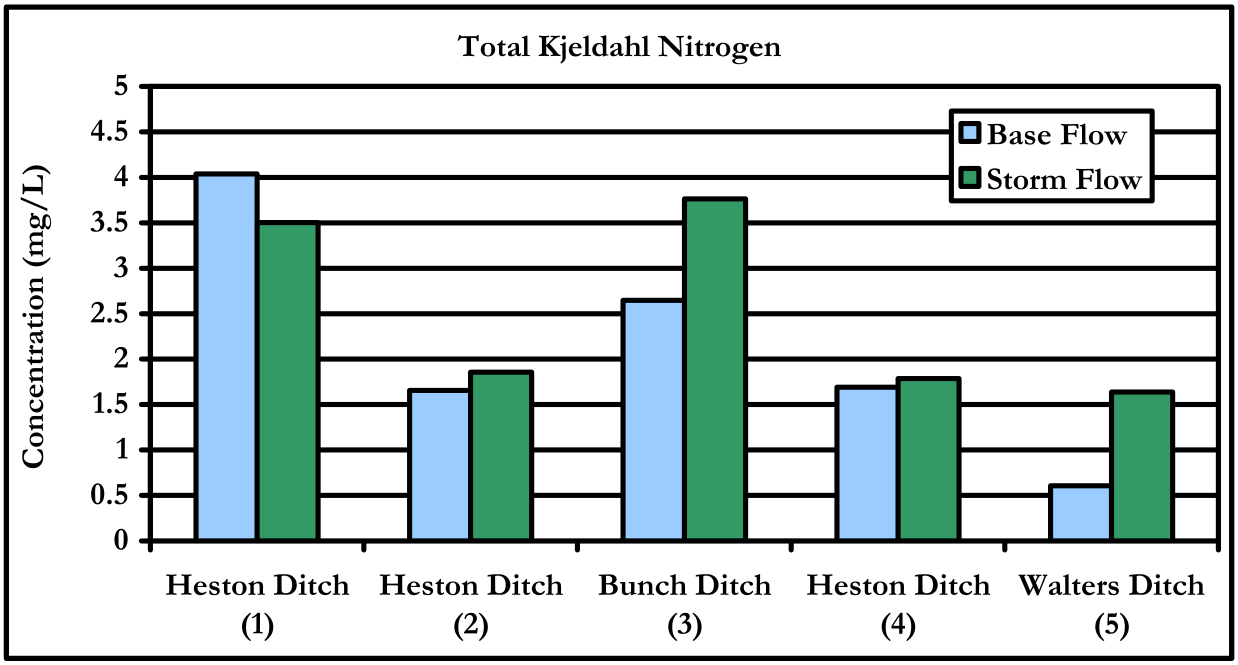

Figure 22. Total Kjeldahl nitrogen concentrations in Pleasant and Riddles Lakes watershed streams as sampled July 19, 2005 (base flow) and July 25, 2005 (storm flow).

Soluble reactive phosphorus (SRP) is the dissolved component of total phosphorus. Understanding what portion of the total phosphorus concentration is dissolved aids in directing management efforts. Dissolved phosphorus usually comes from fertilizer and waste (wildlife and human). Chemical reactions within the stream can also contribute to the dissolved phosphorus levels in the stream. SRP concentrations in the Pleasant and Riddles Lakes watershed streams were higher than desired for headwater streams. SRP concentrations in the Pleasant and Riddles Lakes watershed streams ranged from 0.014 mg/L in Heston Ditch between Pleasant and Riddles Lakes (Site 4) to 0.349 mg/L in Bunch Ditch (Site 3) during base flow, while SRP concentrations ranged from 0.026 mg/L at Heston Ditch between Pleasant and Riddles Lakes (Site 4) to 0.306 mg/L in Walters Ditch (Site 5) during storm flow (Figure 23). High SRP concentrations were also observed in the Heston Ditch headwaters (Site 1) during storm flow, in Bunch Ditch (Site 3) during base and storm flows, and in Walters Ditch (Site 5) during storm flow. SRP concentrations measured at these three sites exceeded the total phosphorus concentration (0.1 mg/L) recommended by the Ohio EPA for the protection of aquatic biota. Heston Ditch headwaters (Site 1), Bunch Ditch (Site 3), and Walters Ditch (Site 5) also possessed relatively high *E. coli* concentrations during base and/or storm flow. Waste (wildlife and/or human) may be increasing the SRP concentrations in these streams. Management efforts should focus on reducing the waste reaching these streams. Nutrient (fertilizer) management should also be a priority on agricultural and residential land in these subwatersheds.

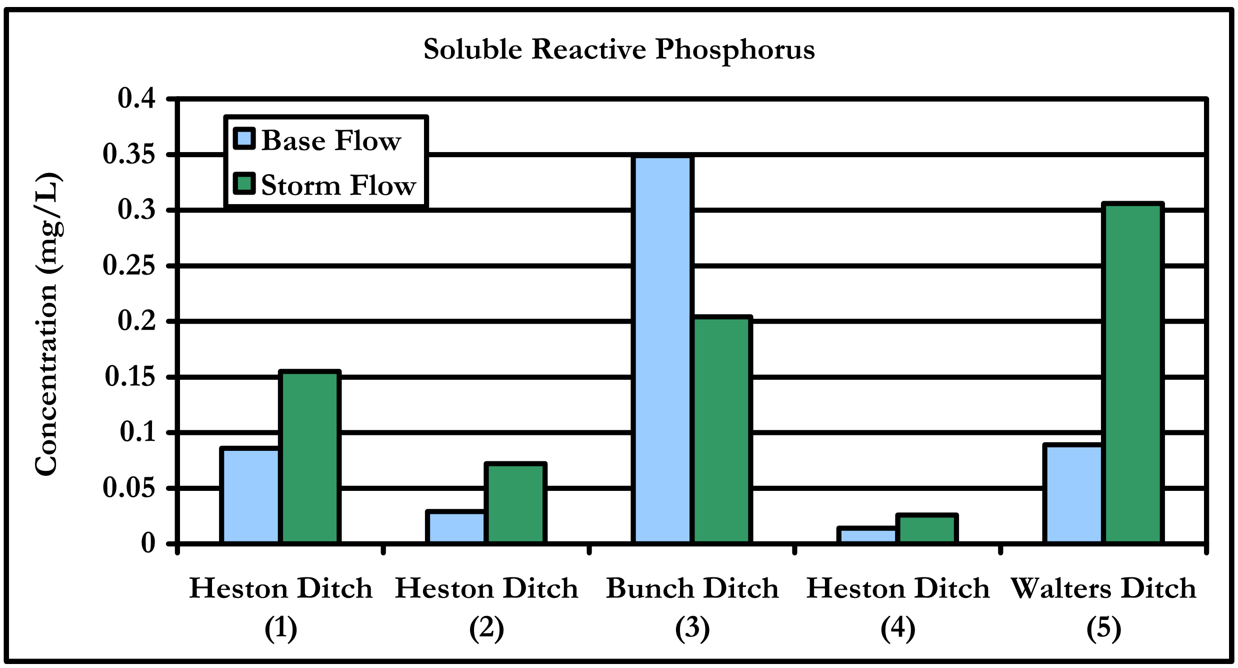

Figure 23. Soluble reactive phosphorus concentrations in Pleasant and Riddles Lakes watershed streams as sampled July 19, 2005 (base flow) and July 25, 2005 (storm flow).

Like the TKN levels, total phosphorus concentrations in the Pleasant and Riddles Lakes watershed streams were high for northern Indiana streams (Figure 24). Under base flow conditions, total phosphorus concentrations ranged from 0.156 mg/L in Heston Ditch upstream of Pleasant Lake (Site 2) to 0.786 mg/L in Bunch Ditch (Site 3). During storm flow, total phosphorus concentrations ranged from 0.179 mg/L in Heston Ditch between Pleasant and Riddles Lakes (Site 4) to 0.534 mg/L in Walters Ditch (Site 5). Bunch Ditch during base flow and Walter Ditch during storm flow also possessed the highest soluble reactive phosphorus concentrations. Based on the elevated total phosphorus concentrations in the streams, these streams were fairly productive streams. Furthermore, this high productivity has the potential to impair the streams' biotic communities. All of the streams possessed base and storm flow total phosphorus concentrations that would place the streams in the eutrophic, or highly productive, category using Dodd et al.'s (1998) criteria. Total phosphorus concentrations in all of the watershed streams under base and storm flow conditions exceeded the USEPA recommended target criterion of 0.076 mg/L (USEPA, 2000a). Similarly, total phosphorus concentrations in all of the watershed streams exceeded the Ohio EPA's recommended total phosphorus criterion to protect aquatic life (0.1 mg/L) in wadeable warmwater habitat streams (Ohio EPA, 1999). Bunch Ditch (Site 3) during base flow, Heston Ditch headwaters (Site 1) during base and storm flow, and Walters Ditch (Site 5) during storm flow also exceeded the total phosphorus criterion (0.34 mg/L) suggested by the Ohio EPA for modified warmwater habitat streams. The high total phosphorus concentrations observed in the watershed streams, particularly in Bunch Ditch, the Heston Ditch headwaters, and Walters Ditch, may be impairing the streams' biotic communities.

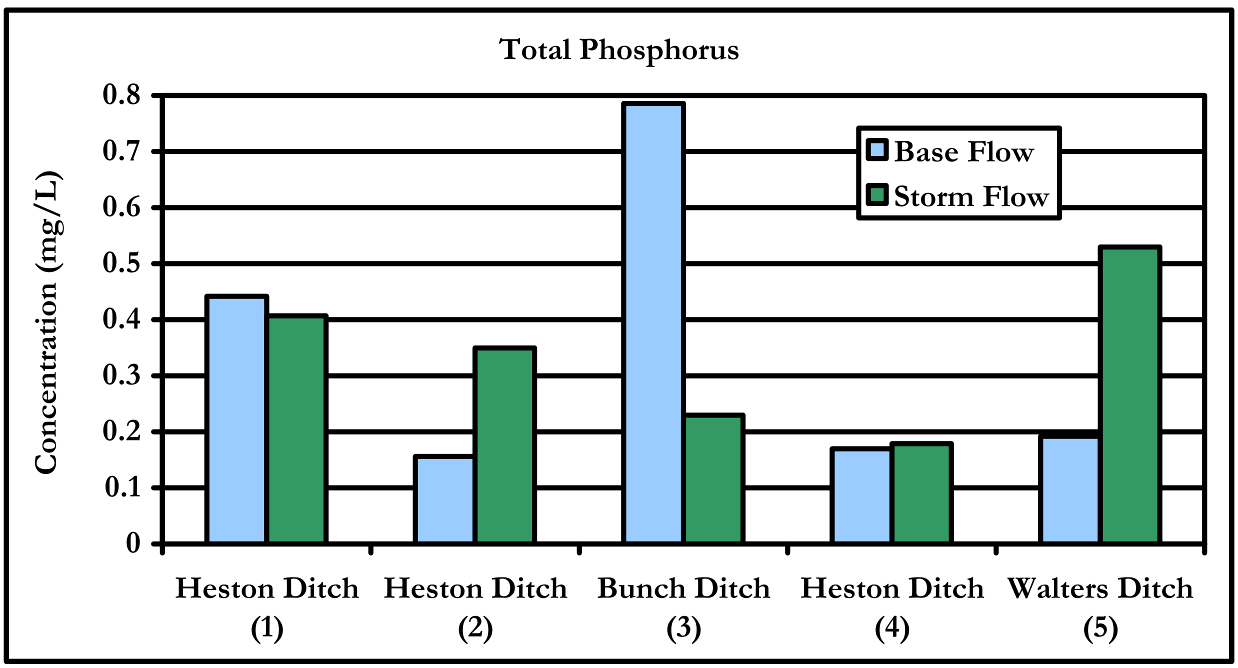

Figure 24. Total phosphorus concentrations in Pleasant and Riddles Lakes watershed streams as sampled July 19, 2005 (base flow) and July 25, 2005 (storm flow). Detection limit is 0.010 mg/L.

E. coli concentrations in the Pleasant and Riddles Lakes watershed streams were relatively high. All but one of the water quality samples collected from the Pleasant and Riddles Lakes watershed streams contained *E. coli* concentrations that violated state water quality standards (Figure 25). In addition to violating the state standard, *E. coli* concentrations at four of the sampling sites were above the average *E. coli* concentration of 650 col/100mL found in Indiana waters (White, unpublished data). *E. coli* concentrations in the Pleasant and Riddles Lakes watershed streams ranged from 130 col/100mL in the Heston Ditch upstream of Pleasant Lake (Site 1) during base flow to 800,000 col/100mL in Bunch Ditch (Site 3) during storm flow. Bunch Ditch (Site 3) and Walters Ditch (Site 5) exhibited high *E. coli* concentrations during both base and storm flow sampling efforts, while the Heston Ditch headwaters (Site 1) exhibited a high *E. coli* concentration during storm flow. During storm flow Bunch Ditch possessed an *E. coli* concentration that is nearly 3400 times the Indiana state standard. Only *E. coli* concentrations in Heston Ditch upstream of Pleasant Lake (Site 2) and between Pleasant and Riddles Lakes (Site 4) during base flow could be considered low. Because *E. coli* is killed by UV light, it is not unusual to observe low *E. coli* concentration downstream of lakes, particularly under normal or base flow conditions. Water in lakes is exposed to light for a prolonged period. This phenomenon is exhibited in Heston Ditch between Pleasant and Riddles Lakes (Site 4) which possessed one of the lowest *E. coli* concentrations during both base and storm flow.

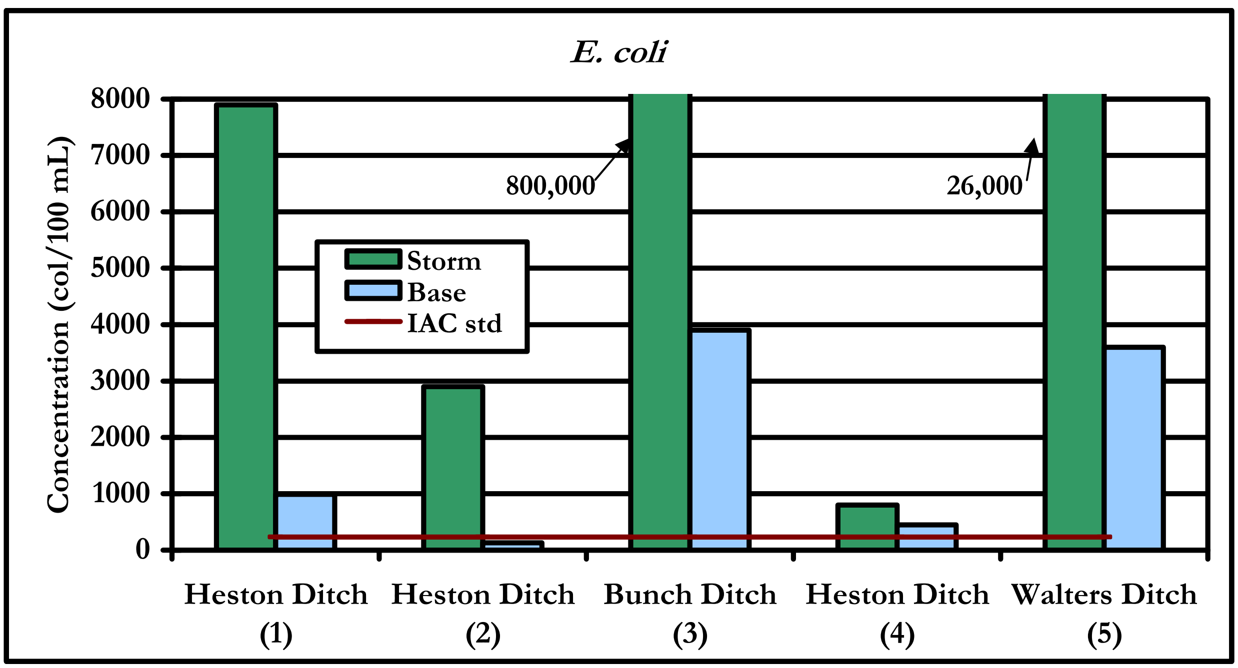

Figure 25. *E. coli* concentrations in Pleasant and Riddles Lakes watershed streams as sampled July 19, 2005 (base flow) and July 25, 2005 (storm flow). The red line indicates the Indiana state standard (235 colonies/100 mL).

Chemical and Sediment Loading
Table 16 lists the chemical and sediment loading data for the Pleasant and Riddles Lakes watershed sites. Figures 26 to 31 present mass loading information graphically.

Table 16. Chemical and sediment load characteristics of the Pleasant and Riddles Lakes watershed streams on July 19, 2005 (base flow) and July 25, 2005 (storm flow).

Site	Date	Timing	Nitrate Load (kg/d)	Ammonia Load (kg/d)	TKN Load (kg/d)	SRP Load (kg/d)	TP Load (kg/d)	TSS Load (kg/d)
1	7/19/05	Base	0.001	0.064	0.259	0.006	0.032	4.064
	7/25/05	Storm	0.038	0.433	1.160	0.055	0.144	6.618
2	7/19/05	Base	0.024	0.096	1.075	0.027	0.145	11.283
	7/25/05	Storm	0.445	0.558	5.522	0.217	1.057	54.355
3	7/19/05	Base	0.002	0.015	0.060	0.009	0.019	0.422
	7/25/05	Storm	5.932	4.068	12.563	0.772	0.871	4283.984
4	7/19/05	Base*	--	--	--	--	--	--
	7/25/05	Storm	0.098	0.300	11.759	0.173	1.191	90.927
5	7/19/05	Base	0.045	0.006	0.028	0.004	0.009	0.882
	7/25/05	Storm	12.121	0.955	1.588	0.363	0.631	25.602

*Flow was negligible during base flow sampling; therefore, loading rates could not be calculated.

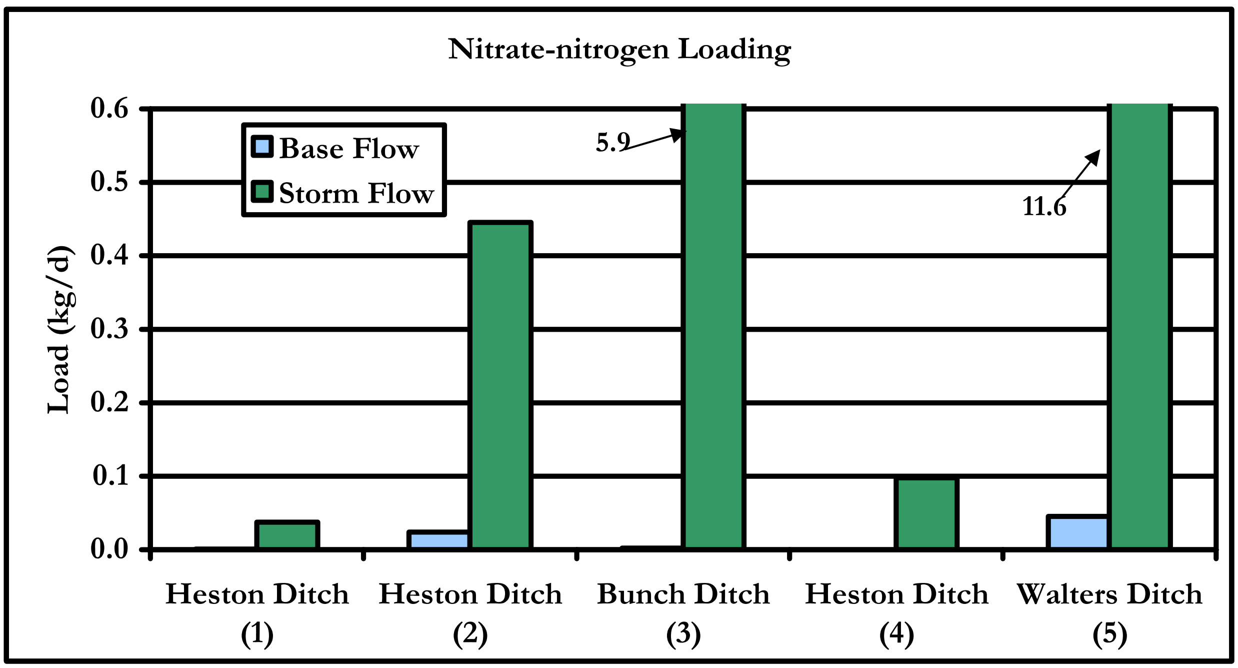

Figure 26. Nitrate-nitrogen loads in Pleasant and Riddles Lakes watershed streams as sampled July 19, 2005 (base flow) and July 25, 2005 (storm flow).

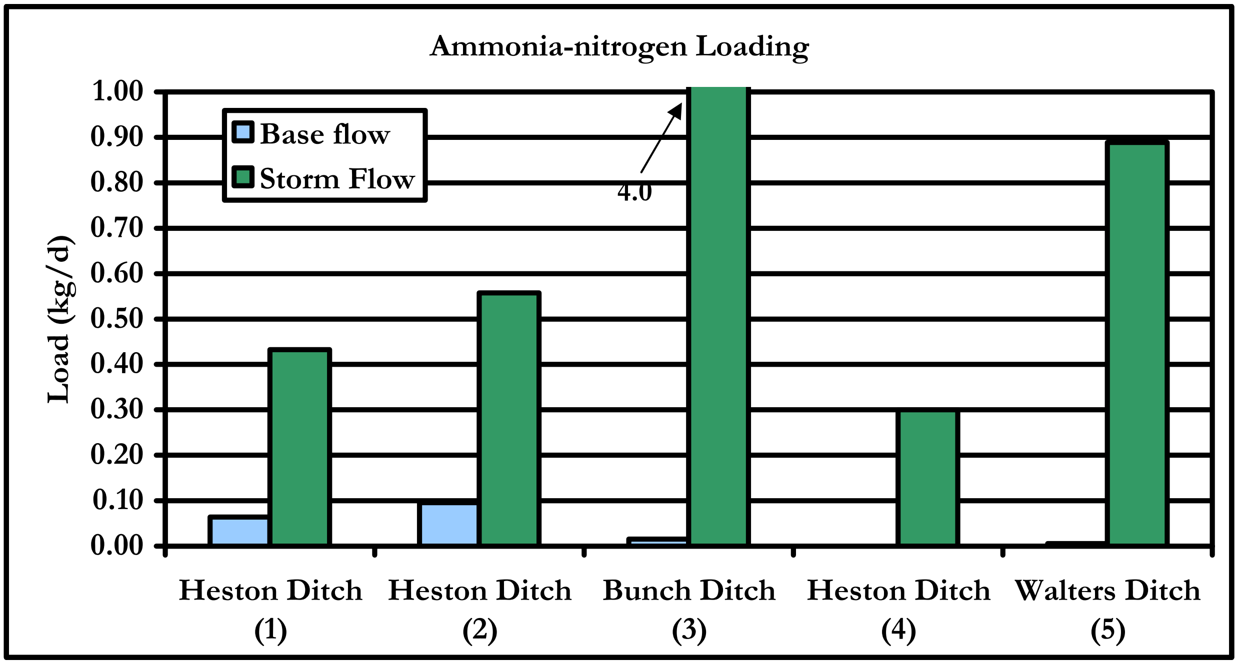

Figure 27. Ammonia-nitrogen loads in Pleasant and Riddles Lakes watershed streams as sampled July 19, 2005 (base flow) and July 25, 2005 (storm flow).

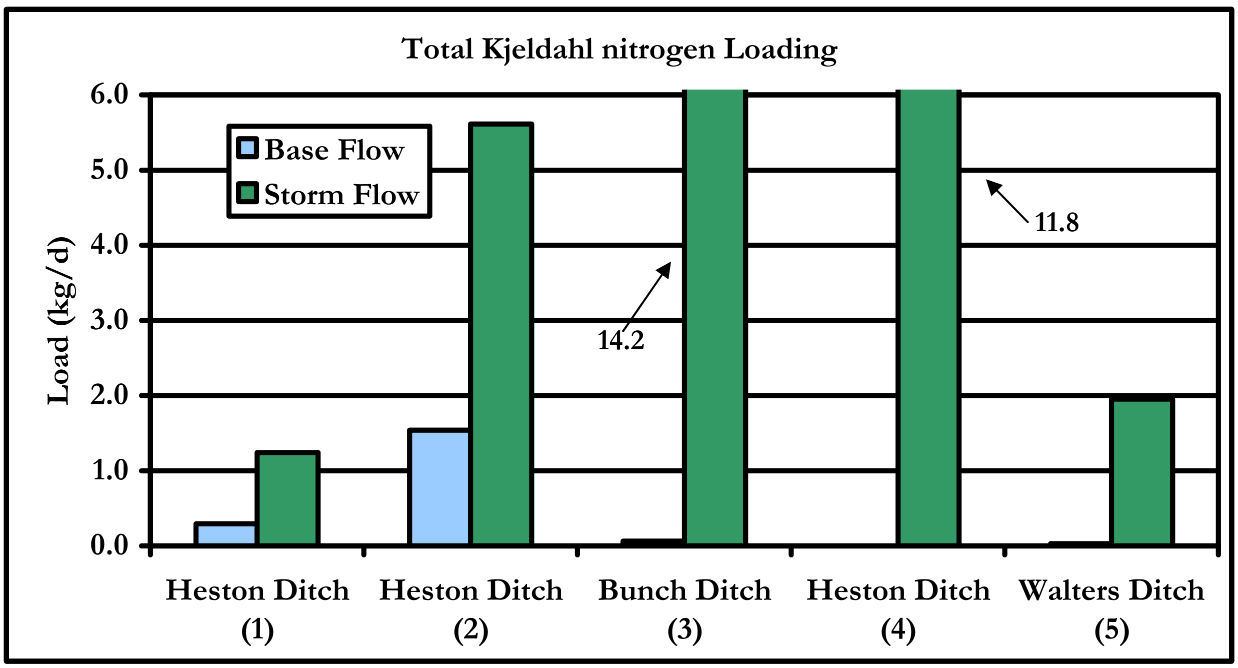

Figure 28. Total Kjeldahl nitrogen loads in Pleasant and Riddles Lakes watershed streams as sampled July 19, 2005 (base flow) and July 25, 2005 (storm flow).

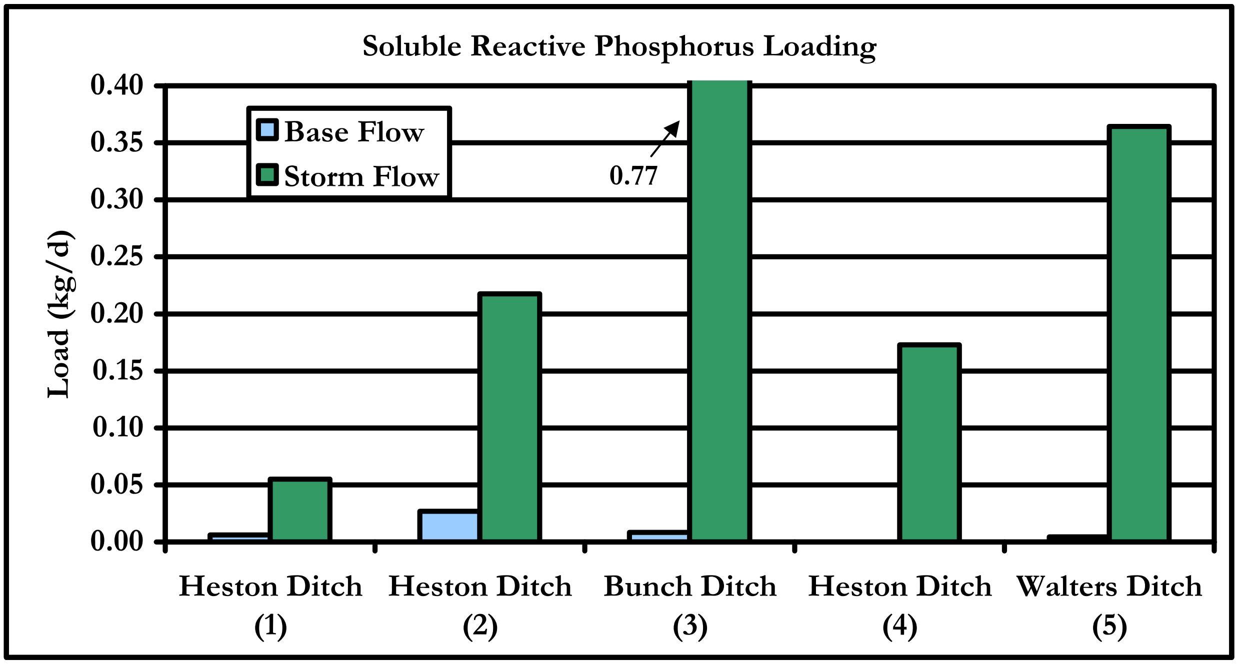

Figure 29. Soluble reactive phosphorus loads in Pleasant and Riddles Lakes watershed streams as sampled July 19, 2005 (base flow) and July 25, 2005 (storm flow).

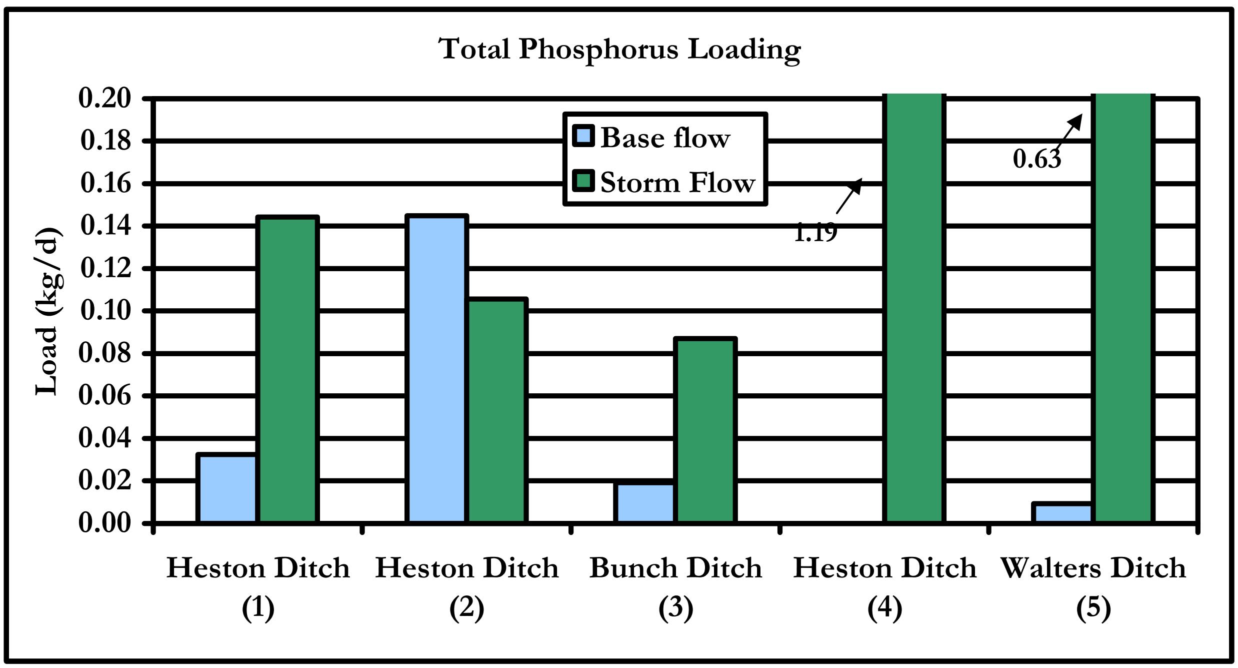

Figure 30. Total phosphorus loads in Pleasant and Riddles Lakes watershed streams as sampled July 19, 2005 (base flow) and July 25, 2005 (storm flow).

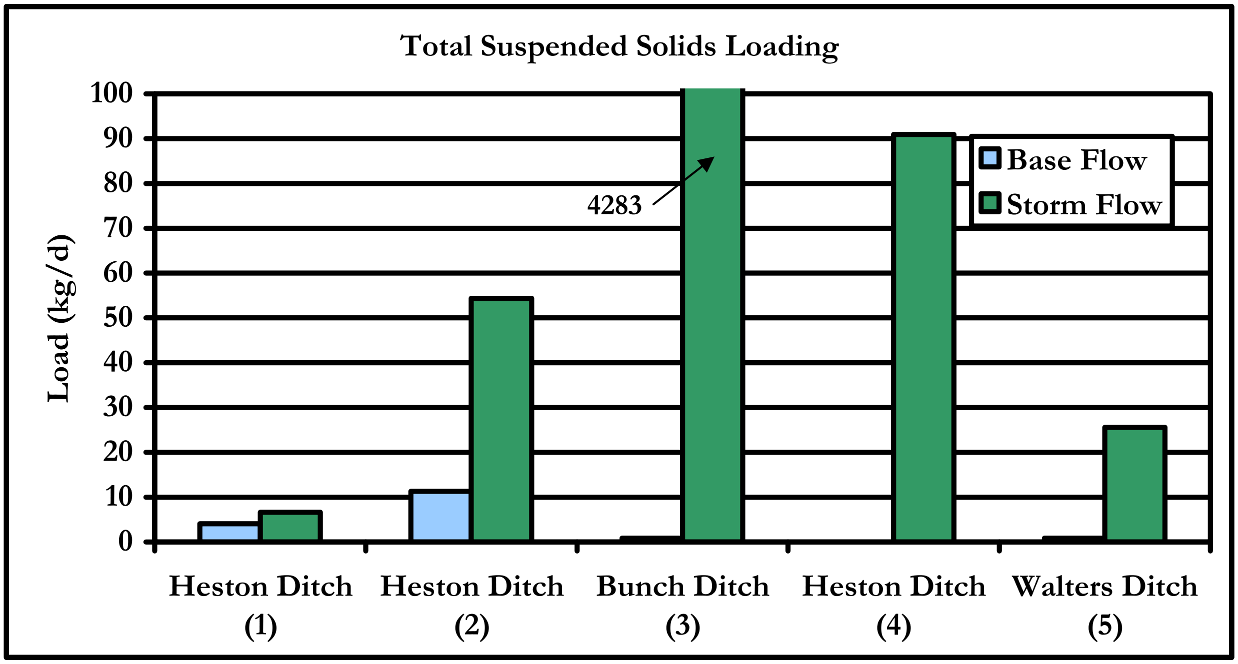

Figure 31. Total suspended solids loads in Pleasant and Riddles Lakes watershed streams as sampled July 19, 2005 (base flow) and July 25, 2005 (storm flow).

While pollutant concentration data provides an understanding of the water quality at a given time and the conditions to which stream biota are subjected, pollutant loading data provides an understanding of how much actual pollutant (mass) is delivered to a downstream waterbody per unit of time. For example, an inlet stream that has high pollutant concentrations does not necessarily contribute the greatest amount of pollutants to its downstream lake. If the inlet stream possesses a very low discharge (i.e. water flow), it likely does not transport as much pollution to the lake as other inlets to the lake that have higher discharge levels. Thus, is it important to evaluate inlet streams' pollutant loading rates to fully understand which inlet is contributing the greatest amount of pollutants to a lake. This information is essential to prioritizing watershed management.

When each of the watershed streams is compared to one another (Figures 26 to 31), one notices that the Bunch Ditch (Site 3) possessed the highest loading rate for most of the pollutants measured during storm flow, while Heston Ditch upstream of Pleasant Lake (Site 2) possessed the highest loading rate for most pollutants during base flow. The only exceptions to this are Walters Ditch (Site 5) which possessed the highest nitrate-nitrogen load during the base and storm flow events. Of concern is the elevated loading values observed in Bunch Ditch during storm flow. This stream possesses the smallest drainage area, yet contained the highest nutrient and sediment loading rates. This indicates that anthropogenic forces are likely impacting water quality in the Bunch Ditch subwatershed. That Heston Ditch upstream of Pleasant Lake (Site 2) had the greatest loading rates, particularly for sediment and particulate nutrient pollutants, is not surprising. This portion of the stream possesses the greatest watershed area which is not buffered by a lake and therefore has the greatest potential for pollutant delivery. In-stream and in-lake chemical processes effect the transport of dissolved nutrients, so it is not unusual for variations in the magnitude of dissolved nutrient loading rates to occur between sampling stations as occurred in the Pleasant and Riddles Lakes watershed streams.

Knowing that Heston Ditch upstream of Pleasant Lake (Site 2) possessed the greatest pollutant loading rates does little to help direct watershed management efforts, so it is useful to consider which streams possessed the highest pollutant loading rates based on watershed size. It is also important to evaluate ***areal pollutant loading rates*** of the streams in determining prioritization of watershed management efforts. The areal pollutant loading rate normalizes the pollutant loading rates by drainage size. By dividing the pollutant loading rate of a stream by the drainage (or watershed) size of the stream, one obtains a *per acre pollutant loading rate*. Thus, pollutant loading rates in streams with large drainages, which are expected to have high pollutant loading rates, are directly comparable to pollutant loading rates in streams with small drainages, which are expected to have lower pollutant loading rates.

Examination of the areal pollutant loading rates for each of the inlet streams (Table 17) shows that, in general, Heston Ditch upstream of Pleasant Lake (Site 2) and Bunch Ditch (Site 3) delivered more pollutants per acre of watershed than the other Pleasant and Riddles Lakes watershed streams. Pollutant delivery rates per acre of watershed in Walters Ditch (Site 5) and the Heston Ditch headwaters (Site 1) are also of concern, but they generally were not as high as the areal loading rates observed in Bunch Ditch and Heston Ditch upstream of Pleasant Lake. These results suggest that management efforts to reduce pollutant loading to the watershed lakes should focus on the Bunch Ditch and Heston Ditch subwatersheds. Theoretically, treatment efforts in these subwatersheds will provide the greatest benefit per acre of treatment.

Table 17. Areal pollutant loading rates for the Pleasant and Riddles Lakes watershed streams on July 19, 2005 (base flow) and July 25, 2005 (storm flow).

Site	Date	Timing	Nitrate Load (kg/ha-yr)	Ammonia Load (kg/ha-yr)	TKN Load (kg/ha-yr)	SRP Load (kg/ha-yr)	TP Load (kg/ha-yr)	TSS Load (kg/ha-yr)
1	7/19/05	Base	0.001	0.039	0.159	0.004	0.020	2.49
	7/25/05	Storm	0.023	0.266	0.711	0.034	0.088	4.06
2	7/19/05	Base	0.008	0.030	0.342	0.009	0.046	3.59
	7/25/05	Storm	0.142	0.177	1.756	0.069	0.336	17.29
3	7/19/05	Base	0.002	0.012	0.047	0.007	0.015	0.33
	7/25/05	Storm	4.611	3.161	9.764	0.600	0.677	3329.50
4	7/19/05	Base	--	--	--	--	--	--
	7/25/05	Storm	0.015	0.045	1.771	0.026	0.179	13.69
5	7/19/05	Base	0.042	0.006	0.026	0.004	0.009	0.81
	7/25/05	Storm	11.185	0.881	1.466	0.335	0.582	23.62

Riddles Lake

Of the two inlets to Riddles Lake, Walters Ditch contributes more pollutants to Riddles Lake compared to Heston Ditch. The only exception was during storm flow when Heston Ditch exhibited a higher total Kjeldahl nitrogen loading rate. These results are somewhat surprising given that Heston Ditch drains more than six times as much land as Walters Ditch. However, even when areal loading rates are compared to account for drainage size, Walters Ditch still generally delivers more pollutants to Riddles Lake per acre of watershed. These results suggest *watershed management efforts to improve water quality in Riddles Lake* should target Walters Ditch for the most part. Efforts to curb sediment transport to the lake should also prioritize treatment in the Heston Ditch subwatershed.

Pleasant Lake

Two of the watershed streams sampled as part of this study represent the two major subwatersheds of Pleasant Lake: the Heston Ditch subwatershed and the Bunch Ditch subwatershed. The headwater of one of these streams, Heston Ditch, was also sampled during this study. Understanding which stream (and therefore which subwatershed) delivers more pollutants will help direct management efforts for restoring Pleasant Lake. As noted above, Bunch Ditch (storm) and Heston Ditch (base) possessed the highest pollutant loading rates for most of the pollutants measured in this study. Bunch Ditch also exhibited some of the highest areal pollutant loading rates in the study, and Heston Ditch's areal pollutant loading rates were of concern. Combined, this data suggest that *management efforts to improve water quality in Pleasant Lake* should focus on treating the Bunch Ditch subwatershed for all pollutants and the Heston Ditch subwatershed specifically for reducing phosphorus and sediment loading.

3.3.2 Macroinvertebrates and Habitat

The results of the macroinvertebrate survey assist with directing watershed management decisions. Walters Ditch possessed the highest quality macroinvertebrate community scored with an mIBI of 4.2, which rates as slightly impaired. This stream's macroinvertebrate community was dominated by a mix of moderately tolerant and moderately intolerant species. The other two streams, Heston Ditch and Bunch Ditch, each possessed a moderately impaired macroinvertebrate community dominated by moderately tolerant to very tolerant species. (Appendix E presents a list of macroinvertebrate families collected at each site.) The streams' overall mIBI scores ranged from a low of 2.0 in Bunch Ditch to 2.7 in Heston Ditch (Table 18). Although these streams' scores differ slightly, both streams fell into the same biotic integrity class. Karr and Chu (1999) indicate that differences between scores *within* an integrity class are not statistically significant; these differences within integrity classes often reflect the large variability associated with sampling natural biological communities rather than true differences in community quality.

Table 18. Summary of classification scores and mIBI scores for each stream sampling site within the Pleasant and Riddles Lakes watershed, July 19, 2005.

	Heston Ditch Site 2	Bunch Ditch Site 3	Walters Ditch Site 5
HBI	0	0	4
Number of Taxa (families)	4	4	4
Number of Individuals	0	0	2
Percent Dominant Taxa	4	6	4
EPT Index	0	0	2
EPT Count	0	0	2
EPT Count/Total Count	0	0	4
EPT Abundance/Chironomid Abundance	8	0	8
Chironomid Count	8	8	8
mIBI Score	**2.7**	**2.0**	**4.2**

The individual metrics that make up the mIBI highlight the differences between the macroinvertebrate communities in the watershed stream. The Hilsenhoff Family Biotic Index (HBI), which uses tolerance values for each family, varies between Walters Ditch and Bunch and Heston Ditches. In Walters Ditch, the presence of more intolerant families generates a lower HBI score (4.6) compared to the HBI scores for Heston and Bunch Ditches (7.6). The presence of large numbers of tolerant members of the Hemipteran family *Corixidae* in Heston Ditch and the Amphipod family *Talitridae* in Bunch Ditch indicates that these ditches possess more tolerant species than those present in Walters Ditch. The evenness of the taxa differed among streams as well. In Bunch Ditch, members of the *Talitridae* family comprised 39% of the total macroinvertebrates collected, while in Heston Ditch, members of the order Gastropoda account for 45% of the total macroinvertebrates collected. By comparison, the more tolerant *Hydropsychidae* family dominated the taxon in Walters Ditch accounting for 36% of the total macroinvertebrate community. The streams supported varying number of EPT (*Ephemeroptera, Plecoptera*, and *Trichoptera*) taxa. Heston Ditch and Bunch Ditch were home to zero and one EPT taxon, respectively, while Walters Ditch supported three EPT taxa. Densities of EPT individuals were also different among the three streams. Heston and Bunch Ditches possessed a total of one EPT individual, while Walters Ditch possessed a total of 33 EPT individuals. Given these differences in individual metrics among the watershed streams, it may be useful to consider each of the streams' macroinvertebrate communities individually.

Heston Ditch (Site 2)
Low individual density and low taxa diversity characterize Heston Ditch's macroinvertebrate community (Table 19). Only one member of the EPT taxa was identified within Heston Ditch, a member of the Ephemeroptera family *Caenidae*. This family is considered silt tolerant; therefore, its presence in Heston Ditch is not surprising. Members of the *Talitridae* family, in the order *Amphipoda*, dominate the stream's macroinvertebrate community accounting for 38% of the community. The silty substrate present at the Heston Ditch sampling site is ideal habitat for *Amphipoda*, so the dominance of this family at this sampling site is not surprising. Members of the very tolerant *Lestidae* and *Libellulidae* families were subdominant components of Heston Ditch's macroinvertebrate community. Members of the *Libellulidae* family are very tolerant to low dissolved oxygen and highly eutrophic conditions. The stream's Hilsenhoff family biotic index (HBI) was 7.62 indicating substantial organic pollution is likely in the stream. The water chemistry results do not necessarily agree with this assessment. Habitat impairment may be influencing the biotic community at this site more than water quality. Overall, the stream's mIBI score was 2.7, suggesting its macroinvertebrate community is moderately impaired.

Table 19. Raw metric scores, classification scores, and mIBI score for Heston Ditch (Site 2), July 19, 2005.

mIBI Metric	Raw Score	Metric Score
HBI	7.62	0
Number of Taxa (family)	14	4
Number of Individuals	49	0
% Dominant Taxa	38.8	4
EPT Index	1	0
EPT Count	1	0
EPT Count/Total Count	0.02	0
EPT Count/Chironomid Count	MAX	8
EPA Abundance/Chironomid Abundance	0	8
Chironomid Count	0	8
	mIBI Score	**2.7**

Bunch Ditch (Site 3)

Moderately tolerant (*Lemnaeidae*) and very tolerant (*Physidae*) families of the Gastropoda (snail) order dominate Bunch Ditch's macroinvertebrate community. Individuals from the two most tolerant families account for nearly half of the stream's total macroinvertebrate population. The stream's HBI score reflects the dominance of extremely tolerant families (Table 20). The stream's elevated HBI score of 7.64 is indicative of substantial organic pollution. The water chemistry sampling supports this. Heston Ditch exhibited relatively high total phosphorus and total organic nitrogen concentrations at base and storm flow. The stream did not support any EPT families. Overall, the stream's mIBI score was 2.0, suggesting its macroinvertebrate community is moderately to severely impaired.

Table 20. Raw metric scores, classification scores, and mIBI score for Bunch Ditch (Site 3), July 19, 2005.

mIBI Metric	Raw Score	Metric Score
HBI	7.64	0
Number of Taxa (families)	12	4
Number of Individuals	72	0
% Dominant Taxa	25.0	6
EPT Index	0	0
EPT Count	0	0
EPT Count/Total Count	0.00	0
EPT Count/Chironomid Count	0	0
EPT Abundance/Chironomid Abundance	0	8
Chironomid Count	7.64	0
	mIBI Score	**2.0**

Walters Ditch (Site 5)

Unlike the other watershed streams, moderately tolerant (*Hydropsychidae* and *Crangonyctidae*) families dominate Walters Ditch. The ditch possessed the highest diversity with 14 families represented in the macroinvertebrate community (Table 21). Three of the families found in Walters Ditch were EPT families, which accounted for more than one-third of the macroinvertebrate community. The ditch's HBI score was 4.59, indicating that limited organic pollution was likely in the stream. The results of the water chemistry assessment showed the ditch has low total organic nitrogen levels relative to the other watershed streams. Habitat may also play a role in the observed slightly impaired mIBI score of 4.2.

Table 21. Raw metric scores, classification scores, and mIBI score for Walters Ditch (Site 5), July 19, 2005.

mIBI Metric	Raw Score	Metric Score
HBI	4.59	4
Number of Taxa (families)	14	4
Number of Individuals	83	2
% Dominant Taxa	36.1	4
EPT Index	3	2
EPT Count	33	2
EPT Count/Total Count	0.40	4
EPT Count/Chironomid Count	33.00	8
EPT Abundance/Chironomid Abundance	1	8
Chironomid Count	4.59	4
	mIBI Score	4.2

3.2.3 Habitat

In addition to a stream's water chemistry, habitat quality also influences the quality of the biotic community inhabiting the stream. Thus, it is useful to examine the habitat quality of the stream in the Pleasant and Riddles Lakes watershed. Table 22 presents the results of the QHEI calculated at each of the five study sites. (Appendix F presents the QHEI data sheets for each of the five study sites.) The following paragraphs provide a short description of the in-stream and riparian characteristics observed at each of the study sites.

Table 22. QHEI Scores for the Pleasant and Riddles Lakes watershed streams, July 19, 2005.

Site	Substrate Score	Cover Score	Channel Score	Riparian Score	Pool Score	Riffle Score	Gradient Score	Total Score
Maximum Possible Score	20	20	20	10	12	8	10	**100**
Heston Ditch (1)	1	6	5	4.5	0	0	4	**20.5**
Heston Ditch (2)	1	10	5	8	0	0	4	**28**
Bunch Ditch (3)	7	11	8	9	4	0	6	**45**
Heston Ditch (4)	1	11	8	10	0	0	2	**32**
Walters Ditch (5)	2	13	8	9	4	0	4	**40**

Heston Ditch Headwaters (Site 1)

Old field and fenced pasture surround Heston Ditch at the sampling site (Figure 32). The riparian buffer zone was negligible along both banks measuring less than 3 feet (0.9 m) wide. However, herbaceous vegetation fully covered the streambanks along this reach. Instream cover at the site was sparse with overhanging vegetation and some woody debris dominating the available cover. There was very little bank erosion present along this reach. The stream possessed low sinuosity and lacks pool and riffle development. This is likely a result of historic dredging operations. The prominent substrate at the site was a muck and silt with extensive embeddedness. Site 1 scored the poorest habitat of the Pleasant and Riddles Lakes watershed streams with a QHEI score of 20.5 out of 100.

Figure 32. Heston Ditch Headwaters (Site 1) sampling location.

Heston Ditch upstream of Pleasant Lake (Site 2)

Forests, open fields, and commercial properties surround Heston Ditch at the sampling site. The riparian zone was a mixture of old fields and forests at the stream site (Figure 33). The riparian buffer was narrow extending nearly 30 feet (9.1 m) from the left bank and between 30 and 150 feet (9.1 and 45.7 m) on the right bank. The stream buffer vegetation consisted of trees, shrubs, and herbaceous material. A moderate amount of instream cover was present along this reach including overhanging vegetation and woody debris. There was very little streambank erosion present in this reach. The stream site sinuosity was low and pool and riffle development was negligible. This suggests that channelization occurred in the past; the stream had not yet appeared to recover. Muck and silt were the dominant substrate types. The substrate was extensively embedded. Substrate condition and the lack of pool-riffle development largely contributed to the low QHEI score of 28 out of 100 points.

Figure 33. Heston Ditch upstream of Pleasant Lake (Site 2) sampling location.

Bunch Ditch (Site 3)

Forest and old field habitat surround Bunch Ditch at the sampling site (Figure 34). The width of the riparian buffer was very wide measuring greater than 150 feet (45.7 m) on the left bank and moderate (between 30 and 150 feet (9.1 to 45.7 m)) on the right bank. Vegetation within the buffer consisted of mostly trees and herbaceous material. Overhanging vegetation and aquatic macrophytes provided moderate instream cover. There was no evidence of bank erosion at the site. Low sinuosity and poor pool and riffle development indicated that the stream was recovering from channelization. The dominant substrate in the stream was muck and sand, though detritus and gravel were also present in lower quantities. The substrate was moderately embedded and covered with a moderate layer of silt. Pools measuring less than 1.2 feet (0.4 m) were observed within the stream channel. The amount of instream cover, the presence of multiple substrate types, and the presence of pools, even with limited development, contributed to a QHEI score of 45 points out of 100, the highest of any of Pleasant and Riddles Lakes watershed.

Figure 34. Bunch Ditch (Site 3) sampling location.

Heston Ditch between Pleasant and Riddles Lakes (Site 4)

Wetlands dominated the land use surrounding the stream site. The riparian zone adjacent to both streambanks was very wide (greater than 150 feet (45.7 m)) and consisted of dense trees and woody vegetation (Figure 35). Instream cover was moderate consisting of overhanging vegetation, aquatic macrophytes, and woody debris. No signs of bank erosion were observed along this reach. Some channelization had occurred in the past, but the riparian growth indicated that the stream channel was recovering along with limited in-channel sinuosity. It should be noted that this reach also lacked pool-riffle development. The dominant substrate within the stream was muck which was extensively embedded. The poor substrate score coupled with the lack of pool-riffle complexes contribute to the low QHEI score (32 out of 100).

Figure 35. Heston Ditch between Pleasant and Riddles Lakes (Site 4) sampling location.

Walters Ditch (Site 5)

Dominant land use adjacent to Walters Ditch was forest. The forested riparian zone was wide measuring greater than 150 feet (45.7 m) on the right bank and less than 30 feet (9.1 m) wide along the left bank. Walters Ditch possessed the highest instream cover score. Shallows in slow water, root wads, overhanging vegetation, undercut banks, aquatic macrophytes, and woody debris all contribute to the moderate instream cover present in Walters Ditch (Figure 36). Bank erosion along this reach was also negligible. Low sinuosity and poor pool riffle development indicate that recent channelization occurred along this site. However, the stream showed moderate stability and appeared to be recovering. The dominant substrate components were muck and silt; artificial substrate and detritus were observed in the stream. The presence of the high quality riparian zone, moderate levels of instream cover, and limited pool development led to the second highest QHEI score (42 out of 100) within the Pleasant and Riddles Lakes watershed.

Figure 36. Walters Ditch (Site 5) sampling location.

The QHEI scores help explain the low biotic integrity scores observed in the Pleasant and Riddles Lakes watershed streams. The QHEI scores indicate that instream and riparian habitat is impaired at all sites. Bunch and Walters Ditches possessed the highest QHEI scores of 45 and 40, respectively. These scores suggest that both streams should be capable of supporting a moderately healthy warmwater fauna. Both of these streams possessed QHEI scores in IDEM's "partially supportive" range. However, Bunch Ditch's macroinvertebrate community rated as moderately impaired while Walters Ditch's macroinvertebrate community rated only slightly impaired. Thus, it is likely that water quality played a greater role in impairing the biotic community at Bunch Ditch than habitat quality. QHEI scores of the remaining watershed streams indicate severe habitat impairment. In these streams (Heston Ditch at three reaches), both poor water quality and poor habitat quality play a role in impairing the streams' biotic communities.

Many of the sites share some common characteristics. Riffles are absent or poorly developed in each of the watershed streams. Many of the streams offer only run habitat to aquatic biota. This lack of habitat diversity leads to a lack of biotic diversity since different organisms occupy different habitat types, or ***niches***, within a stream. The watershed streams also lack in-stream cover. This is especially true in the Heston Ditch headwaters. Substrate quality is relatively poor in each of the watershed streams. The dominance of muck/silt substrate, heavy silt covering, and embeddedness of the substrate resulted in exceptionally poor substrate quality scores in Heston Ditch (headwaters, upstream and Pleasant Lake, and between Pleasant and Riddles Lakes) and Walters Ditch. Riparian cover was noticeably better in Heston Ditch between Pleasant and Riddles Lakes. Overall, habitat quality is generally poor in the Pleasant and Riddles Lakes watershed streams and restoration measures are necessary to ensure healthy, functioning stream systems.

4.0 LAKE ASSESSMENT

4.1 Morphology

4.1.1 Riddles Lake

Table 23 presents Riddles Lake's morphology. The lake itself is long and narrow with a northwest to southeast orientation (Figure 37). The lake consists of two deeper holes surrounded by even shallower water (Figure 38). The lake's deepest point lies in the southern portion of the 77-acre (31.2-ha) lake. Here, the lake extends to it maximum depth of 20 feet (6.1 m; Table 23). One shallower hole lies in the northern portion of the lake reaching a depth of 15 feet (4.6 m). Water as shallow as 10 feet (3.1 m) surrounds these holes. Because the lake's maximum depth is only 20 feet (6.1 m), the lake is considered a shallow lake (Cooke et al., 2005). Based on this distinguishing characteristic, the lake requires special management needs. More information on these needs is included in the management section of this report.

Table 23. Morphological characteristics of Riddles Lake.

Characteristic	Value
Surface Area	77 acres (31.2 ha)
Volume	624 acre-feet (769,682 m^3)
Maximum Depth	20 feet (6.1 m)
Mean Depth	8.1 feet (2.5 m)
Shallowness Ratio	0.35
Shoalness Ratio	1.0
Shoreline Length	9,749 feet (2,971 m)
Shoreline Development Ratio	1.46

Figure 37. Aerial photograph of Riddles Lakes. Scale: 1"=600'.

Figure 38. Riddles Lake bathymetric map. Source: IDNR, 1955. Scale: 1"=440'.

Riddles Lake has large expanses of shallow water. According to its depth-area curve (Figure 39), 27 acres (10.9 ha) of the lake is covered by water less than 5 feet (1.5 m) deep, while the entire lake (77 acres or 31.2 ha) is covered by water less than 20 feet (6.1 m) deep. This translates into a moderate shallowness ratio of 0.35 (ratio of area less than 5 feet (1.5 m) deep to total lake area) and a high shoalness ratio of 1.0 (ratio of area less than 20 feet (6.1 m) deep to total lake area) (Table 23), as defined by Wagner (1990). Riddles Lake can be characterized as a shallow lake (≤ 30 feet deep; Cooke et al., 2005) and as described above, this characterization should be taken into account when determining management options for the lake.

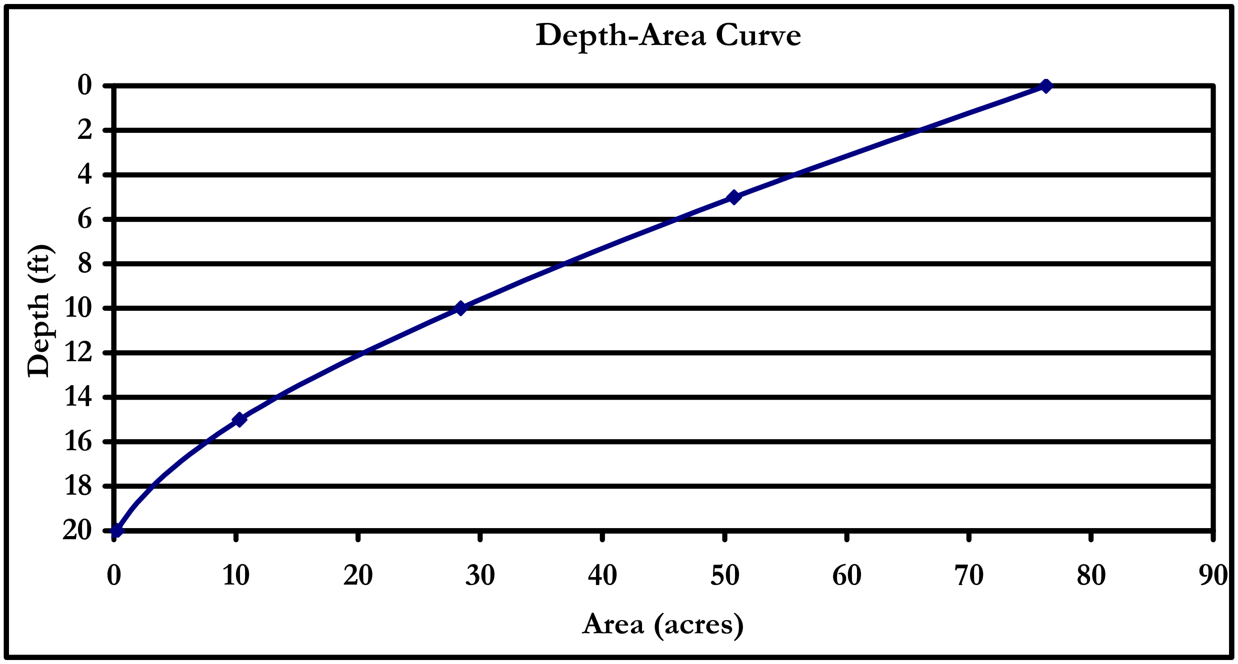

Figure 39. Depth-area curve for Riddles Lake.

Riddles Lake holds approximately 624 acre-feet (769,682 m^3) of water. As illustrated in the depth-volume curve (Figure 40), most of the lake's volume is contained in the more shallow areas of the lake. Nearly 96% of the lake's volume is contained in water that is less than 10 feet (3.1 m) deep. The lake's volume gradually increases with depth to a water depth of about 10 feet (3.1 m). Below 10 feet (73.1 m), the steep curve indicates a greater change in depth per unit volume.

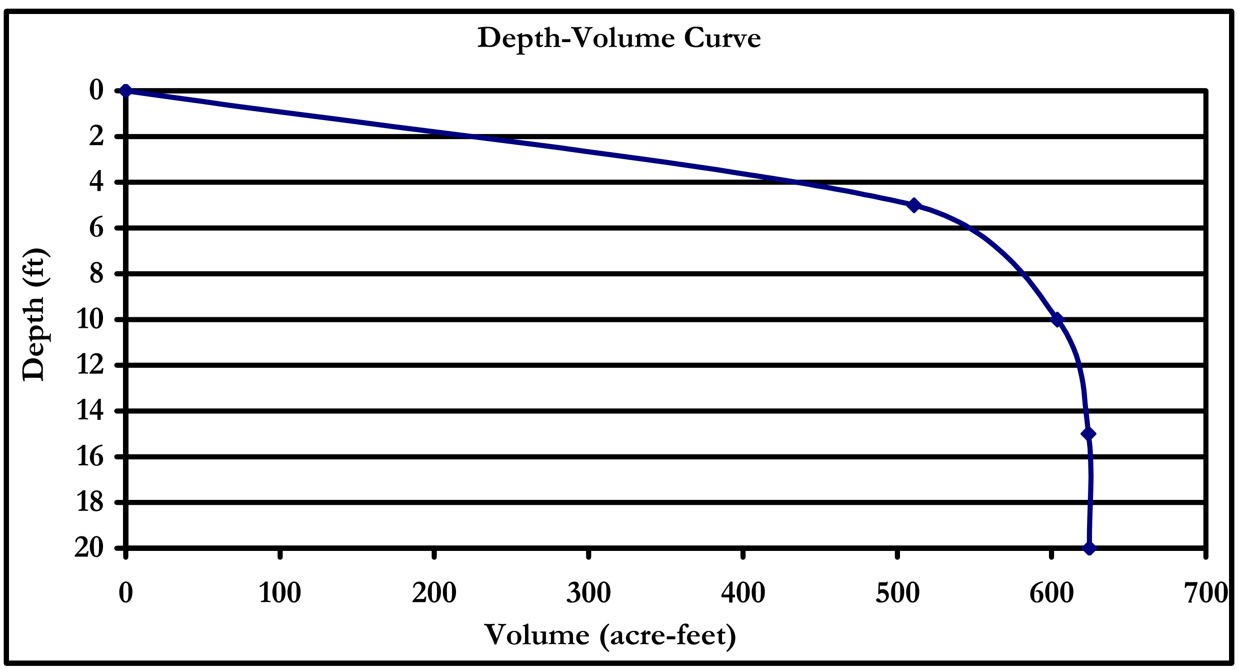

Figure 40. Depth-volume curve for Riddles Lake.

A lake's morphology can play a role in shaping the lake's biotic communities. For example, Riddles Lake's extensive shallow area coupled with its poor clarity suggests that the lake is capable of supporting a relatively high quality rooted plant community. Based on the lake's 1% light level, Riddles Lake's littoral zone (or the zone capable of supporting aquatic rooted plants) extends from the shoreline to the point where water depths are approximately 3.5 feet (1.0 m). Referring to Riddles Lake's depth-area curve (Figure 39), this means that the lake's littoral zone is approximately 19 acres (7.7 ha) in size or approximately 25% of the lake. This size littoral zone can impact other biotic communities in the lake such as fish that use the plant community for forage, spawning, cover, and resting habitat.

A lake's morphology can indirectly influence water quality by shaping the human communities around the lake. The shoreline development ratio is a measure of the development potential of a lake. It is calculated by dividing a lake's shoreline length by the circumference of a circle that has the same area as the lake. A perfectly circular lake with the same area as Riddles Lake (77 acres or 31.2 ha) would have a circumference of 6,492 feet (1,979 m). Dividing Riddles Lake's shoreline length (9,479 feet or 2,889.2 m) by 6,492 feet yields a ratio of 1.46:1. This ratio is relatively low. Like the other lakes in the Pleasant and Riddles Lakes watershed, Riddles Lake lacks extensive shoreline channeling observed on other popular Indiana lakes such as lakes in the Barbee Chain and Lake Tippecanoe. Given the immense popularity of lakes in northern Indiana, lakes with high shoreline development ratios are often highly developed. Increased development around lakes often leads to decreased water quality.

4.1.2 Pleasant Lake

Although the IDNR mapped the depth contours for Pleasant Lake, the bathymetric map for Pleasant Lake could not be located; therefore, depth-area and depth-volume curves were not generated for this lake. However, because the lake was originally mapped and the volume calculated by the IDNR, the IDNR fisheries reports contain volume and mean depth information for Pleasant Lake. These data will be used to detail the morphology of Pleasant Lake. Pleasant Lake is roughly triangular shaped (Figure 41) with the widest area of the lake being located in the northern portion of the lake. Pleasant Lake is a 29 acre (11.7 ha) lake and has one basin. The lake reaches a maximum depth of 39 feet (11.9 m) and possesses an average depth of 17 feet (5.2 m; Table 24). Pleasant Lake holds approximately 663 acre-feet (817,798 m^3) of water. A perfectly circular lake with the same area as Pleasant Lake (29 acres or 11.7 ha) would have a circumference of 3,984 feet (1,214 m). Dividing Pleasant Lake's shoreline length (5,331 feet or 1625 m) by 3,984 feet yields a ratio of 1.34:1. This shoreline development ratio is relatively low. Pleasant Lake lacks extensive shoreline channeling similar to Riddles Lake.

Table 24. Morphological characteristics of Pleasant Lake.

Characteristic	Value
Surface Area	29 acres (11.7 ha)
Volume	663 acre-feet (817,798 m^3)
Maximum Depth	39 feet (11.9 m)
Mean Depth	17 feet (5.2 m)
Shoreline Length	5,331 feet (1,624.9 m)
Shoreline Development Ratio	1.38

Figure 41. Aerial photograph of Pleasant and Fites lakes. Scale: 1"=600'.

4.1.3 Fites Lake

A bathymetric map for Fites Lake has not been completed; therefore, depth-area and depth-volume curves were not generated for this lake. However, general morphological characteristics are known for Fites Lake and are detailed in Table 25. Fites Lake is relatively round in shape (Figure 41). Fites Lake is a 19 acre (7.7 ha) lake which possesses one basin. The lake reaches a maximum depth of 16 feet (4.9 m). A perfectly circular lake with the same area as Fites Lake (19 acres or 7.7 ha) would have a circumference of 3,225 feet (982.9 m). Dividing Fites Lake's shoreline length (3,300 feet or 1,005.8 m) by 3,225 feet yields a ratio of 1.02:1. This ratio is extremely low. Fites Lake lacks shoreline channeling or development typically observed on other popular Indiana lakes.

Table 25. Morphological characteristics of Fites Lake.

Characteristic	Value
Surface Area	19 acres (7.7 ha)
Maximum Depth	16 feet (4.9 m)
Shoreline Length	3,300 feet (1,005.8 m)
Shoreline Development Ratio	1.02

4.2 Shoreline Development

Residential development within Union Township began in 1837 with the first settlements being located along the Michigan Road. Residences spread along Michigan Road, and in 1880, a sawmill and gristmill were built in present day Lakeville. The area was heavily timbered with ash, oak, walnut, and hickory. Lumber and milling were the primary industries of the times (Historic Preservation Society, 2000). Chapman (1880) noted that several lakes were present within the vicinity of Lakeville with Pleasant and Riddles Lakes being the largest and most accessible. Chapman (1880) also indicated that development around these lakes may be difficult due to the mucky and mirey ground forming the shorelines of these lakes.

4.2.1 Riddles Lake

Early aerial photography of Riddles Lake (1938) indicates that the lake's shoreline remained in its natural condition. Thick borders of wetland and forest provided an adequate buffer for the agricultural land located north and east of the lake. Agricultural fields bordered the lake on its southern and western shorelines. No houses or piers could be identified in the 1938 aerial. By 1957, a number of houses and dirt access points occurred around the lake. One residence was located along the northern shoreline of Riddles Lake, while a limited number of houses occurred along the lake's eastern shoreline. The southern and western shorelines remained largely undeveloped. Schnicke (1966) noted that approximately 20% of Riddles Lake's northern and eastern shoreline was developed in 1966. The remaining shoreline was in pasture or marsh at the time of Schnicke's assessment (Schnicke, 1966). In 1974, Peterson noted the presence of nine homes along the shoreline of Riddles Lake (Peterson, 1974) indicating approximately 10% of the shoreline was developed. The 1974 aerial photograph concurs with this estimate. Fisheries assessments completed by Dexter (1986) and Robertson (1988) also concur with Peterson's assessment of 10% development along Riddles Lake's shoreline.

By 2003, shoreline development along Riddles Lake increased with the development of the Riddles Lake Subdivision immediately east of the lake. A number of houses in this subdivision are located adjacent to the eastern shoreline of Riddles Lake (Figure 37). However, IDNR Fisheries Biologists (Price, 2004b) and Indiana Clean Lakes Program staff (CLP, 2004) indicate that only 25% of the lake's shoreline is developed. Assessments completed by JFNew biologists in concert with the plant survey are in general agreement with this estimate (Figure 42). In total, natural shoreline exists along approximately 7,580 feet (2,310 m or 77%) of Riddles Lake's shoreline. JFNew mapped the remaining 2,170 feet (661 m) of shoreline as modified natural (1,640 feet (500 m) or 17%) and (530 feet (161 m) or 5%) as grass. Those residences where emergent vegetation has been removed but some portion of the natural shoreline remains intact are labeled as modified natural. Those areas where all natural vegetation has been removed and replaced by mowed grass are labeled in Figure 42 as grass. Many of the residences along Riddles Lake possess natural vegetation along the lake's shoreline.

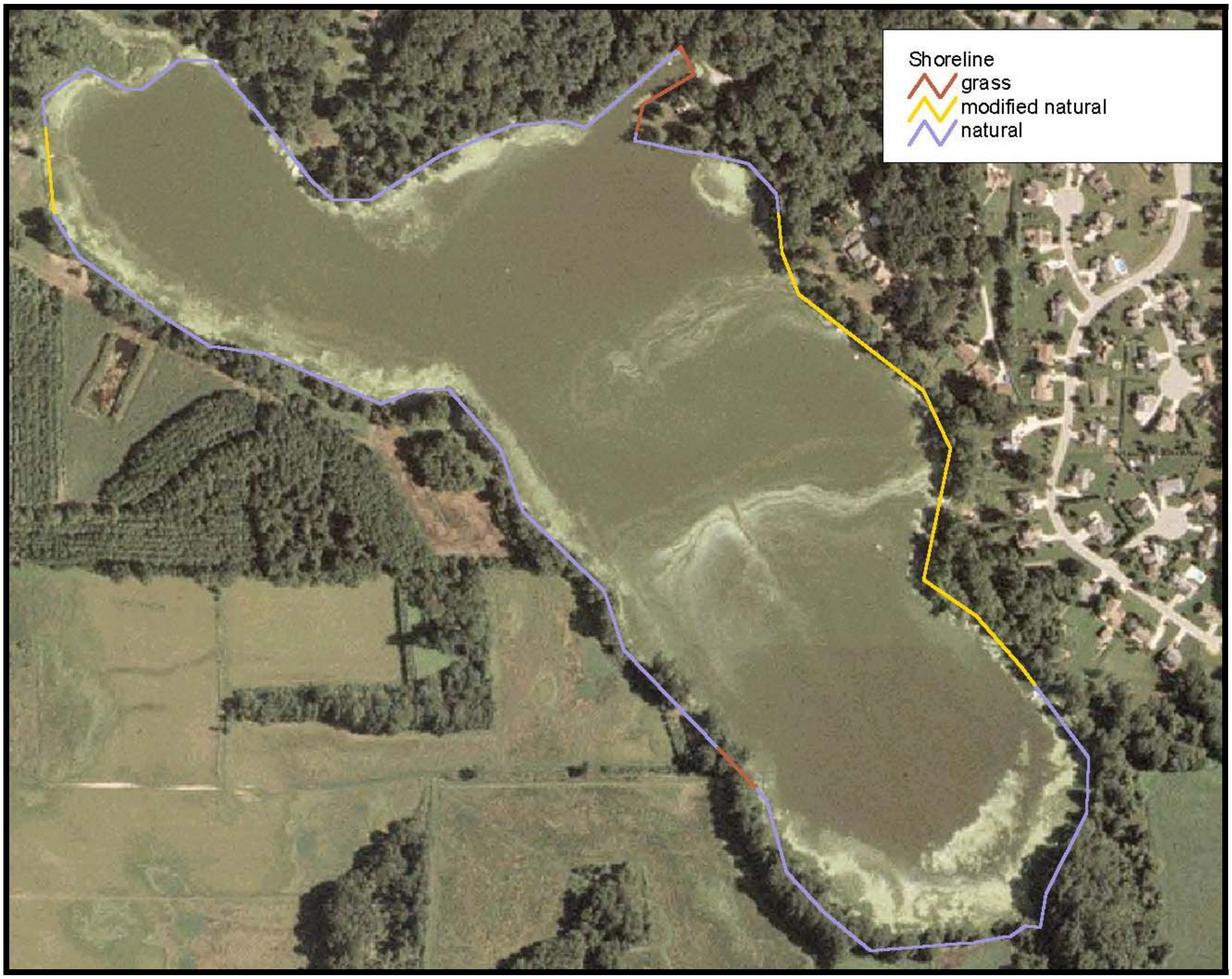

Figure 42. Shoreline type and coverage adjacent to Riddles Lake. Natural refers to those areas of the shoreline which remain in their natural condition with intact submergent, floating, emergent, and shoreline zones along the shoreline. Modified natural refers to those portions of the shoreline where a portion of the natural shoreline has been altered; however, much of the shoreline integrity remains intact. Grass refers to those locations where emergent vegetation has been removed and replaced by mowed grass to the lake's edge.

4.2.2 Pleasant Lake

Early aerial photography of Pleasant Lake (1938) indicates that much of Pleasant Lake's shoreline remained in its natural condition. Thick borders of wetland and forest provided an adequate buffer for the agricultural land located north and south of the lake. No houses or piers could be identified along the lake's shoreline in the 1938 aerial. The 1938 aerial also indicates that the stream now known as Bunch Ditch did not flow into Pleasant Lake, rather it by-passed the lake flowing into Heston Ditch downstream of Pleasant Lake. By 1957, Bunch Ditch's channel was modified to flow into Pleasant Lake and limited growth occurred around the lake. One residence was located along the northern shoreline of Pleasant Lake, while several dirt roads provided access to Pleasant Lake's southern and eastern shorelines.

In 1977, IDNR Fisheries Biologists noted that only 5% of Pleasant Lake's shoreline was developed. This development included one boat rental, several homes, and multiple private camping areas. The remainder of the lakeshore consisted of marshland and woodland with residential areas located north and west of the lake and agricultural fields, marshes, and forest located south and east of the lake (Peterson, 1978). Robertson (1979 and 1987) noted that the shoreline remained largely undeveloped through the late 1980s. IDNR Fisheries Biologists noted that approximately 10% of the lakeshore was developed during their latest assessment completed in 2003 (Price, 2004a). Aerial photographs from the summer of 2003 indicate that this estimate is still accurate (Figure 41). JFNew biologists noted the presence of natural shoreline around much of the lake. The only area where the natural buffer was removed occurs in concert with Kelley's Bait Shop on the northern shoreline of the lake. Even in this area, a limited buffer is present along the lake's shoreline.

4.2.3 Fites Lake

Like Pleasant Lake, the shoreline of Fites Lake remains mostly undeveloped. Aerial photographs (1957, 1972, and 2003) indicate that the forested and wetland buffer remains intact around Fites Lake. Only one small area has been developed for individual use; however, the natural shoreline buffer has not been disturbed in this area (Figure 41).

4.3 Boating History

Boat counts were completed on Pleasant and Riddles Lakes throughout the summer and fall (Tables 26 and 27). As both lakes are primarily fishing lakes, the number of lake users were primarily fishing or cruising. High speed boating is not allowed on either lake; therefore, boat densities are not of high concern. Boat survey information indicates that during summer weekends and holidays, higher boat densities occur on both lakes. It should also be noted that the vast majority of boaters on Riddles Lake are fishing or cruising, which was defined as pontoon boats being used by lakefront residents. This activity typically occurred during the evening hours, while fishing typically occurred in the early morning before noon.

Table 26. Results of boat counts completed during the summer of 2005 on Riddles Lake.

Date	Day of the Week	Fishing	Cruising	Swimming	Kayaking	Canoeing	Total
4/14/05	Thursday	2	--	--	--	--	2
4/16/05	Saturday	5	--	--	--	--	5
4/17/05	Sunday	6	--	--	--	--	6
4/23/05	Saturday	7	--	--	--	--	7
5/4/05	Wednesday	5	--	--	--	--	5
5/8/05	Sunday	8	--	--	--	--	8
5/17/05	Tuesday	6	2	--	--	--	8
5/18/05	Wednesday	7	1	--	--	--	8
5/26/05	Thursday	5	--	--	--	--	5
5/29/05	Sunday	11	4	--	--	--	15
5/30/05	Monday	9	6	--	--	--	15
6/8/05	Wednesday	7	2	--	--	--	9
6/12/05	Sunday	9	3	--	2	--	14
6/30/05	Thursday	4	3	1	--	--	8
7/2/05	Saturday	9	5	--	--	--	14
7/3/05	Sunday	8	6	--	--	--	14
7/4/05	Monday	10	5	--	4	1	20

Date	Day of the Week	Fishing	Cruising	Swimming	Kayaking	Canoeing	Total
7/15/05	Friday	4	--	--	--	--	4
7/30/05	Saturday	7	2	--	--	--	9
8/4/05	Thursday	3	1	--	--	--	4
8/6/05	Saturday	6	3	--	--	--	9
8/21/05	Sunday	7	4	--	--	--	11
9/2/05	Friday	4	2	--	--	--	6
9/3/05	Saturday	7	4	--	--	--	11
9/4/05	Sunday	9	2	--	--	--	11
9/5/05	Monday	9	5	--	--	--	14
9/6/05	Tuesday	4	1	--	--	--	5
9/7/05	Wednesday	5	2	--	--	--	7
9/8/05	Thursday	4	3	--	--	--	7
9/10/05	Saturday	6	2	--	--	--	8
9/11/05	Sunday	6	3	--	2	--	11
9/12/05	Monday	4	--	--	--	--	4
9/13/05	Tuesday	3	--	--	--	--	3
9/14/05	Wednesday	4	--	--	--	--	4
9/15/05	Thursday	3	--	--	--	--	3
9/16/05	Friday	5	--	--	--	3	8
9/17/05	Saturday	7	3	--	3	3	16
9/18/05	Sunday	6	3	--	3	2	14

Table 27. Results of boat counts completed during the summer of 2005 on Pleasant Lake.

Date	Day of the Week	Total
9/4/05	Sunday	14
9/5/05	Monday	14
9/6/05	Tuesday	5
9/7/05	Wednesday	6
9/8/05	Thursday	4
9/9/05	Friday	6
9/10/05	Saturday	12
9/11/05	Sunday	9
9/12/05	Monday	3
9/13/05	Tuesday	5
9/14/05	Wednesday	4
9/15/05	Thursday	3
9/16/05	Friday	2
9/17/05	Saturday	9
9/18/05	Sunday	17
9/19/05	Monday	1

4.4 Historic Water Quality

4.4.1 Riddles Lake Historical Water Quality

The Indiana Department of Natural Resources, Division of Fish and Wildlife, the Indiana State Pollution Control Board, and the Indiana Clean Lakes Program have conducted various water quality tests on Riddles Lake. Table 28 presents some selected water quality parameters for these assessments of Riddles Lake.

Table 28. Summary of historic data for Riddles Lake.

Date	Secchi (ft)	Percent Oxic (%)	Epi pH	Mean TP (mg/L)	Plankton Density (#/L)	TSI Score (based on means)	Source
8/13/64	3.0	79%	8.7	--	--	--	Schnicke, 1966
7/22/74	2.5	29%	8.0	--	--	--	Peterson, 1975
7/30/75	--	--	--	0.110*	--	30^{δ}	IDEM, 1986
7/28/85	2.0	28%	8.0	--	--	--	Dexter, 1986
7/27/87	2.2	67%	9.5	--	--	--	Robertson, 1988
8/20/90	2.9	40%	--	0.300	10,302	32	CLP, 1990
7/25/95	1.3	30%	7.9	0.352	79,298	48	CLP, 1995
7/12/99	2.9	40%	7.1	0.173	16,219	27	CLP, 1999
6/16/03	3.0	44%	9.3	--	--	--	Price, 2004b
7/18/05	2.3	29%	8.9	0.554	16,903	41	Current Study

*Water column average; all other values are means of epilimnion and hypolimnion values.
$^{\delta}$Eutrophication Index (EI) score. The EI differs slightly but is still comparable to the TSI used today.

Taken together, the data in Table 28 suggests that the water quality in Riddles Lake is poorer than most Indiana lakes and has changed little over the past 30 years. Secchi disk transparency depths fluctuated from year to year, but generally changed little since 1974 (Figure 43). All recorded transparencies were poorer than the median transparency depth for Indiana lakes. The poorest Secchi disk transparency depth of 1.3 feet (0.4 m) was recorded in 1995. Additional data indicates that the 1995 assessment likely occurred during an algal bloom. (Data from other area lakes, including Pleasant Lake, indicate that algal blooms were common during the 1995 CLP assessments (JFNew, 2005b).) Total phosphorus concentrations increased from 1974 to 1995 before declining in 1999. The relatively high total phosphorus concentrations exceed the median concentration observed in Indiana lakes. Historic total phosphorus concentrations indicate that Riddles Lake likely supported algal blooms in the summer. The lake's algal (plankton) density reflects the relatively high nutrient levels. Nutrients (phosphorus and nitrogen) promote the growth of algae and rooted plants; thus, lakes with high nutrient levels are expected to support dense algae and/or rooted plant populations. This pattern can be observed in Riddles Lake as well. Riddles Lake's plankton density mimics the pattern of the lake's total phosphorus concentration with the exception of the current assessment. (This variation will be explained in detail in the results and discussion sections.) Based on historical data, the highest observed plankton density occurred in 1995, which corresponds with the highest observed total phosphorus concentration and the poorest Secchi disk transparency.

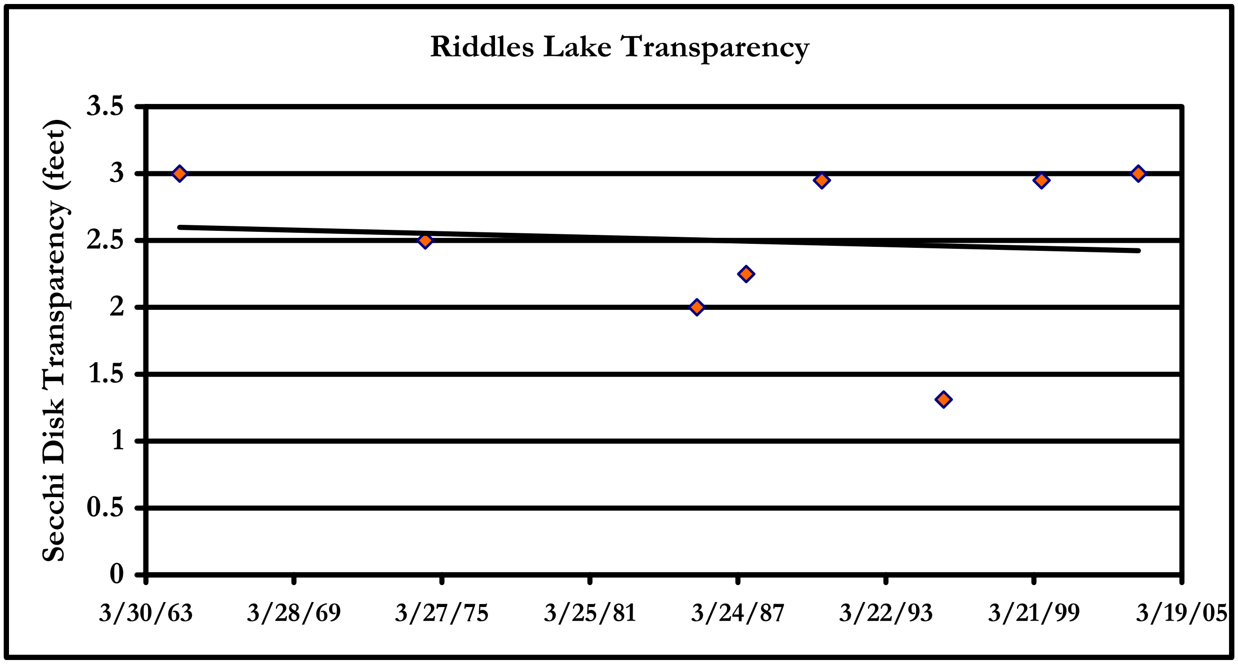

Figure 43. Historical Secchi disk transparencies within Riddles Lake.
Source: Schnicke, 1964; Peterson, 1975; Dexter, 1986; Robertson, 1988; CLP, 1990, 1995, and 1999; Price, 2004b.

The historic Indiana Trophic State Index (ITSI) scores displayed in Table 28 place Riddles Lake in two different productivity classes. The lake's overall ITSI was 30 in 1974, 32 in 1990, and 27 in 1999. These scores suggest that the lake's trophic state was mesotrophic. However, in 1995, the ITSI score increased to 48 while the current assessment's ITSI score was 42, suggesting that the lake's trophic state was hypereutrophic. The difference between the scores is largely due to the change in the algal community composition and density. In 1995, algal density was more than four times that observed during any of the other assessments. Furthermore, blue-green algae dominated the Riddles Lake community during this assessment. As a consequence, more than 15 additional points were added to the lake's ITSI score. These points were enough to move the lake from the mesotrophic to the hypereutrophic category. The weightings of the ITSI based on algal data have been one of the problems with the Indiana TSI. However, Riddles Lake's poor Secchi disk transparencies, high total phosphorus concentrations, and high chlorophyll *a* concentrations would place the lake in the eutrophic to hypereutrophic category during all of the historic Clean Lakes Program assessments if it were evaluated using Carlson's (1977) TSI. Thus, the Indiana TSI score of 48 suggesting that Riddles Lake was hypereutrophic is likely accurate, while ITSI scores from other assessments may underrate Riddles Lake's trophic state. (Please see the following sections for a more detailed discussion of lake water quality parameters and trophic states.)

Consistent with poor Secchi disk transparency depths described above, other parameters indicate that Riddles Lake's clarity is poor. The amount of light that penetrated the lake's water column to a depth of 3 feet (0.9 m) was a maximum of only 12% during the three previous assessments (Tables 29 through 31). In clearer lakes, light transmission at 3 feet (0.9 m) can be expected to exceed 50%. By a depth of 5 feet (1.5 m), light was completely extinguished to the point where photosynthesis could not be supported. This limits the habitat availability for rooted plants.

The data also suggest that Riddles Lake supports a healthy algal population. Riddles Lake contained an elevated epilimnetic pH during the 1964, 1987, 2003, and current assessments. A high epilimnetic pH may indicate the presence of photosynthesizing algae. During the process of photosynthesis, algae remove carbon dioxide, a weak acid, from the water column, thereby increasing the water's pH. Additionally, the concentration of chlorophyll *a* was very high during the 1995 and 1999 assessments measuring 61.8 and 101.3 µg/L, respectively. Chlorophyll *a* concentrations of this magnitude are typically characteristic of hypereutrophic lakes. However, blue-green algae, a nuisance algae generally associated with productive lakes, dominated the Riddles Lake algal community during the 1995 assessment only. During the other two Clean Lakes Program (CLP) assessments, 1990 and 1999, blue-green algae were not the dominant component of the algal community.

Figure 44 displays the temperature profiles recorded during IDNR fisheries surveys and Indiana CLP assessments. The earliest assessment, conducted in August 1964, indicates that Riddles Lake was not thermally stratified at the time of sampling. Rather the lake was mixing to a depth of 16 feet (4.8 m). All of the remaining profiles show that Riddles Lake was stratified, albeit in some cases stratification was weak. For example, the temperature profile recorded by the IDNR during 2003 occurred early in the growing season resulting in weaker stratification than is present during other surveys. The developed hypolimnion present during the 1995 and 1999 surveys is more typical of Indiana lakes.

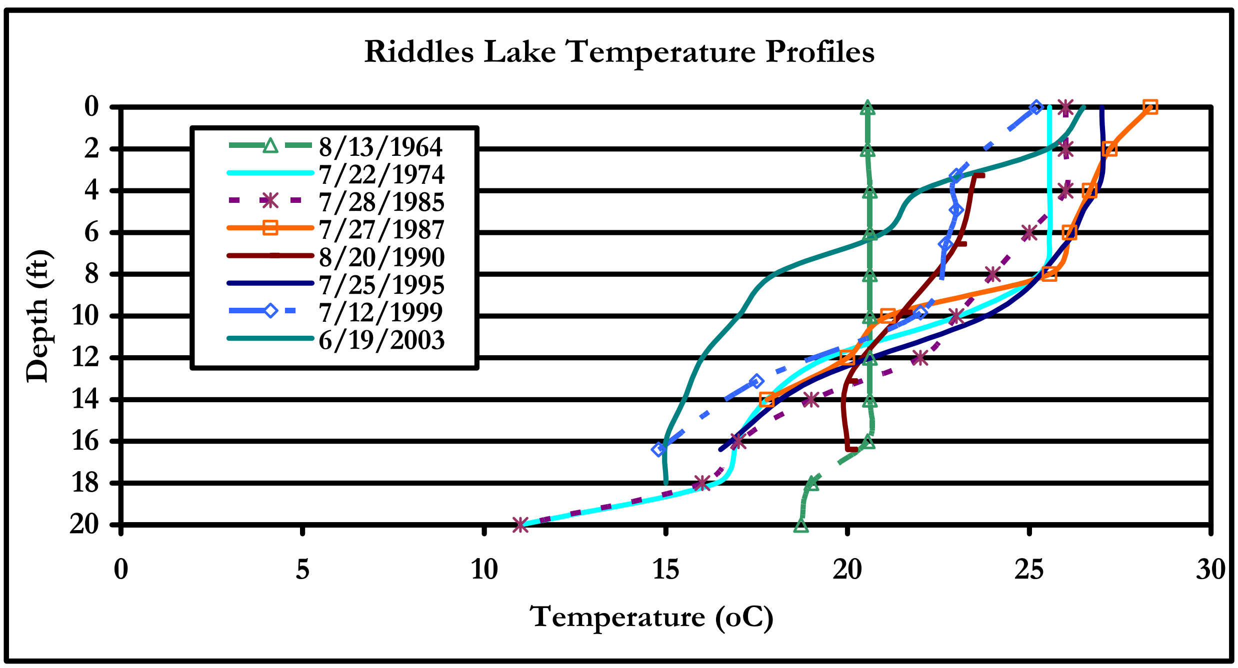

Figure 44. Historical temperature profiles for Riddles Lake.
Source: Schnicke, 1964; Peterson, 1975; Dexter, 1986; Robertson, 1988; CLP, 1990, 1995, and 1999; Price, 2004b.

Much of the data presented above suggest that Riddles Lake is relatively productive. The historical dissolved oxygen results lend further evidence to this suggestion (Figure 45). Dissolved oxygen profiles indicate that the lake was typically anoxic below 5 feet (1.5 m). This decline in dissolved oxygen limits the availability of habitat for the lake's inhabitants and increases the potential for nutrient release from the lake's bottom sediments. Generally, data recorded over the past 30 years indicate that less than 45% of the water column contained sufficient oxygen to support healthy biotic communities (Table 28). However, data from the 1964 and 2003 assessments indicate that more than 65% of the water column contained sufficient oxygen for aquatic biota. The 1964 assessment occurred when the lake was experiencing continuous mixing or turnover (Figure 44). During this assessment, the lake contained relatively low dissolved oxygen concentrations (<5 mg/L) throughout a larger portion of the water column. In fact, dissolved oxygen levels were below the Indiana state standard throughout the water column during the 1964 assessment. If these poor conditions persisted for a prolonged period of time, then aquatic biota likely underwent severe stress. Conversely, the 2003 assessment was recorded earlier in the growing season when oxygen levels are expected to be higher.

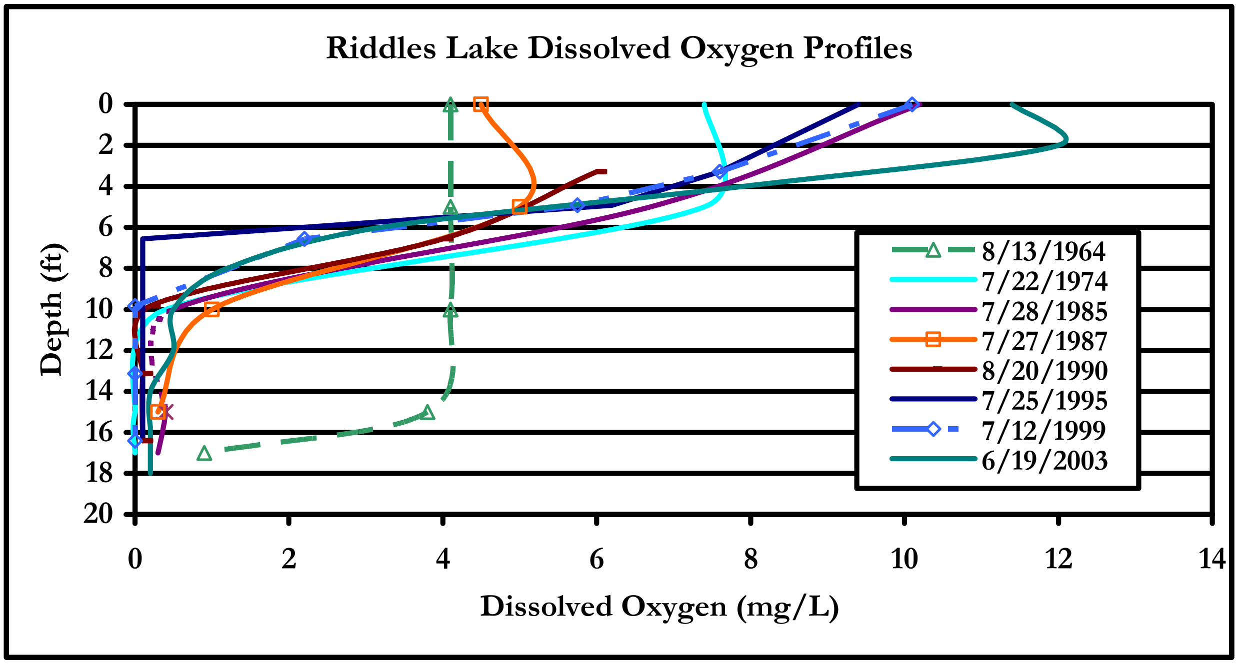

Figure 45. Historical dissolved oxygen profiles for Riddles Lake.
Source: Schnicke, 1964; Peterson, 1975; Dexter, 1986; Robertson, 1988; CLP, 1990, 1995, and 1999; Price, 2004b.

Despite possessing an adequate percentage of the water column that contains sufficient dissolved oxygen for aquatic biota, dissolved oxygen levels were quite low throughout Riddles Lake. The apparent lack of dissolved oxygen is a problem for the lake's inhabitants. Fish and other aquatic organisms require oxygen to live. The lack of oxygen below 5 feet (1.5 m) reduces the amount of habitat available to fish. Respiration by aquatic fauna and decomposition of organic matter likely depleted the dissolved oxygen supply in the lake's deeper water. The lake's elevated hypolimnetic ammonia-nitrogen concentrations suggest that decomposition typically occurs in the lake's hypolimnion (Tables 29 through 31).

The lack of oxygen in Riddles Lake's hypolimnion also affects the lake's chemistry. While mean total phosphorus concentrations are variable for the three years displayed in Tables 29 through 31, a more detailed evaluation shows that hypolimnetic total phosphorus concentrations are much higher than epilimnetic total phosphorus concentrations. Under anoxic conditions, the iron in iron phosphate, a common precipitate in lake sediments, is reduced, and the phosphate ion is released into the water column. This phosphate ion is readily available to algae, and can therefore spur algal growth. Further review of historical phosphorus data indicates that in 1990 and 1995 much of the total phosphorus was in the dissolved form of phosphorus (SRP). SRP accounted for almost half of the total phosphorus within the lake's water column in 1999 as well. This indicates that Riddles Lake was releasing phosphorus from its bottom sediments. Additionally, Riddles Lake exhibited higher hypolimnetic ammonia concentrations than those observed in the lake's epilimnion during the 1990, 1995, and 1999 assessments, suggesting decomposition of organic matter was occurring in the lake's bottom waters. Overall, this data suggest that Riddles Lake was a eutrophic to hypereutrophic lake during the 1990, 1995, and 1999 assessments.

Table 29. Historical water quality characteristics of Riddles Lake, August 20, 1990.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
Secchi Depth Transparency	0.9 m	-	6
Light Transmission @ 3 ft.	12%	-	4
Total Phosphorus	0.094 mg/L	0.506 mg/L	4
Soluble Reactive Phosphorus	0.003 mg/L	0.391 mg/L	4
Nitrate-Nitrogen	0.758 mg/L	0.386 mg/L	2
Ammonia-Nitrogen	0.057 mg/L	1.511 mg/L	3
Organic Nitrogen	1.887 mg/L	1.783 mg/L	3
Oxygen Saturation @ 5 ft.	58%	-	0
Percent Water Column Oxic	40%	-	3
Plankton Density	10,302/L	-	2
Blue-Green Dominance	45.4%	-	0
		TSI Score	**32**

Table 30. Historical water quality characteristics of Riddles Lake, July 25, 1995.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	7.9	6.8	-
Alkalinity	132.5 mg/L	160.8 mg/L	-
Conductivity	350 μmhos	350 μmhos	-
Secchi Depth Transparency	0.4 m	-	6
Light Transmission at 3 ft.	6.5%	-	4
1% Light Level	4.7 ft	-	-
Total Phosphorus	0.115 mg/L	0.589 mg/L	4
Soluble Reactive Phosphorus	0.005 mg/L	0.502 mg/L	4
Nitrate-Nitrogen	0.022 mg/L	0.022 mg/L	0
Ammonia-Nitrogen	0.018 mg/L	1.494 mg/L	3
Organic Nitrogen	1.721 mg/L	2.665 mg/L	4
Oxygen Saturation at 5 ft.	77%	-	0
Percent Water Column Oxic	30%	-	3
Plankton Density	79,298/L	-	10
Blue-Green Dominance	51%	-	10
Chlorophyll *a*	61.8 μg/L	-	-
		TSI Score	**48**

Table 31. Historical water quality characteristics of Riddles Lake, July 12, 1999.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	7.1	6.5	-
Alkalinity	120.3 mg/L	126.5 mg/L	-
Conductivity	342 μmhos	340 μmhos	-
Secchi Depth Transparency	0.9 m	-	6
Light Transmission at 3 ft.	12%	-	4
1% Light Level	5 ft	-	-
Total Phosphorus	0.108 mg/L	0.238 mg/L	3
Soluble Reactive Phosphorus	0.016 mg/L	0.127 mg/L	3
Nitrate-Nitrogen	0.022 mg/L	0.022 mg/L	0
Ammonia-Nitrogen	0.018 mg/L	0.678 mg/L	1
Organic Nitrogen	2.050 mg/L	2.342 mg/L	4
Oxygen Saturation at 5 ft.	67%	-	0
Percent Water Column Oxic	40%	-	3
Plankton Density	16,219/L	-	3
Blue-Green Dominance	40%	-	0
Chlorophyll *a*	101.3 μg/L	-	-
		TSI Score	**27**

4.4.2 Pleasant Lake Historical Water Quality

The Indiana Department of Natural Resources, Division of Fish and Wildlife, the Indiana State Pollution Control Board, and the Indiana Clean Lakes Program have conducted various water quality tests on Pleasant Lake. Table 32 presents some selected water quality parameters for these assessments of Pleasant Lake.

Table 32. Summary of historic data for Pleasant Lake.

Date	Secchi (ft)	Percent Oxic	Epi pH	Mean TP (mg/L)	Plankton Density (#/L)	TSI Score (based on means)	Source
7/30/75	3.4	--	--	0.110*	--	29$^{\delta}$	IDEM, 1975
5/24/77	2.9	29%	9.1	--	--	--	Armstrong, 1977
7/10/78	2.5	14%	8.5	--	--	--	Robertson, 1979
7/12/86	2.0	20%	10.0	--	--	--	Robertson, 1987
8/20/90	2.6	38%	--	0.102	1,720	33	CLP, 1990
7/25/95	2.9	25%	8.2	0.272	75,987	49	CLP, 1995
7/12/99	2.3	38%	7.5	0.147	2,158	25	CLP, 1999
6/16/03	2.5	27%	9.8	--	--	--	Price, 2004
8/9/04	2.9	38%	8.6	0.121	5,572	28	CLP, 2004a
7/18/05	2.3	24%	9.0	0.403	43,036	42	Current Study

*Water column average; all other values are means of epilimnion and hypolimnion values.
$^{\delta}$Eutrophication Index (EI) score. The EI differs slightly but is still comparable to the TSI used today.

Based on parameters displayed in Table 32, Pleasant Lake's water quality appears to have changed little over the past 30 years (Figure 46). Secchi disk transparency depths fluctuated from year to year, but have generally changed little since 1975. All recorded transparencies were poorer than the median transparency for Indiana lakes. The poorest transparency measurement (2 feet or 0.6 m) was recorded in 1986, while the best transparency measurement (3.4 feet or 1.0 m) occurred in 1975. Total phosphorus concentration also varied over time with all concentrations below the median value measured in Indiana lakes except the 1995 sampling and the current assessment. Prior to the current assessment, the highest total phosphorus concentration (0.272 mg/L) was measured during the 1995 assessment. In general, Pleasant Lake's historic total phosphorus concentrations were relatively normal for Indiana lakes. However, these concentrations place Pleasant Lake in the eutrophic and hypereutrophic categories using Vollenweider's (1975) data and Carlson's (1977) TSI, respectively. Historic total phosphorus concentrations indicate that Pleasant Lake likely supported algal blooms in the summer. The lake's algal (plankton) density reflects the lake's nutrient levels. The highest historic observed plankton density corresponds with the highest historic total phosphorus concentration recorded in Pleasant Lake. Likewise, the lowest plankton density corresponds with the lowest historic total phosphorus concentration.

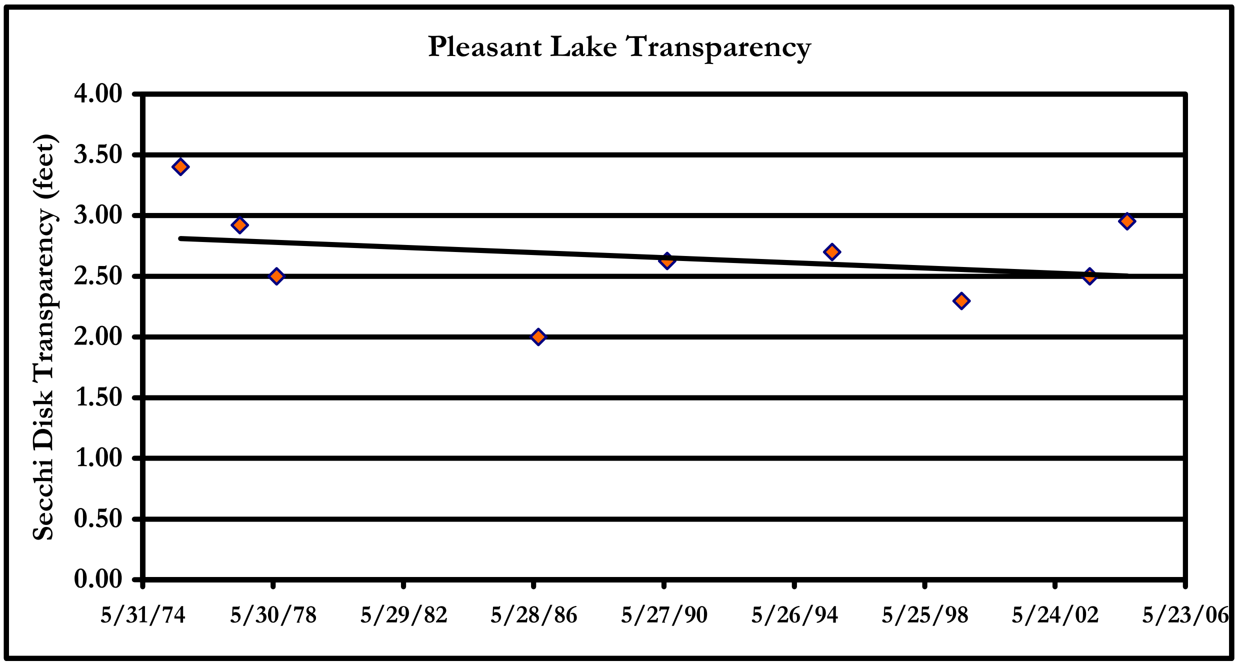

Figure 46. Historical Secchi disk transparencies within Pleasant Lake.
Source: IDEM, 1986; Armstrong, 1978; Robertson, 1979, 1987; CLP, 1990, 1995, 1999, and 2004; Price, 2004a.

ITSI scores for Pleasant Lake place the lake into two different productivity classes. The lake's overall ITSI increased from 25 in 1974 to 33 in 1990. These scores suggest that the lake's trophic state was mesotrophic to eutrophic. However, in 1995, the ITSI score increased again to 49 suggesting that the lake's trophic state was hypereutrophic. Scores calculated for the 1999 and 2004 assessments (25 and 28, respectively) indicate that the lake was again mesotrophic to eutrophic in nature. The current assessment's ITSI score was 42. These variations indicate that the low ITSI score calculated during 1999 and 2004 was due almost entirely to low plankton densities. In 1995, algal density was more than 25 times higher than plankton densities observed during any of the other historic assessment and nearly double the current plankton density. The added points were enough to move Pleasant Lake from the mesotrophic-eutrophic category to the hypereutrophic category. As will be discussed in more depth in the methods and discussion sections, the weightings of the ITSI based on algal data have been one of the problems with the Indiana TSI. Pleasant Lake's poor Secchi disk transparencies elevated total phosphorus concentrations, and high chlorophyll *a* concentrations place the lake in the eutrophic to hypereutrophic range using Carlson's (1977) TSI. Therefore, the Indiana TSI score of 49 calculated for 1995, suggesting that Pleasant Lake was hypereutrophic at that time is likely accurate.

Other parameters suggest that water clarity within Pleasant Lake remains poor, but that clarity may be improving. The amount of light that penetrated Pleasant Lake's water column to a depth of 3 feet (0.9 m) measured a maximum of 11% in the 1990's. Data collected during 2004 indicate that light penetration improved slightly with 25% of available light reaching 3 feet (0.9 m). The observed light levels are still below levels anticipated in deeper lakes where light levels at 3 feet (0.9 m) typically exceed 50%. The maximum depth of light penetration also increased from those observed during the 1990's assessments to the 2004 assessment. During the 1990's, at a depth of 6 feet (1.8 m), light was completely extinguished to a point where photosynthesis could not be supported. During the 2004 assessment, light penetrated nearly twice as deep as observed during previous assessments reaching a depth of 13 feet (3.9 m). Data suggest that something other than algal growth is limiting light penetration within Pleasant Lake. As the penetration of light limits the ability for rooted plant growth, lake residents could expect increased rooted plant growth if water clarity, and thus light penetration, continues to improve.

Historical data also suggests that Pleasant Lake supported a healthy algal population. Pleasant Lake contained an elevated epilimnetic pH during the 1977, 1986, and 2003 assessments. A high epilimnetic pH can indicate the presence of photosynthesizing algae. The highest epilimnetic pH measured in Pleasant Lake occurred during the 1986 assessment, which corresponds with the lowest Secchi disk transparency depth observed at Pleasant Lake. Together, this data suggest that the assessment occurred during an algal bloom. Supersaturated dissolved oxygen levels present within the upper 5 feet (1.5 m) of the water column during the 2003 assessment lend further evidence to the presence of photosynthesizing algae during this assessment. Additionally, chlorophyll *a* concentrations were elevated during the 1995, 1999, and 2004 assessments ranging from 20.1 to 148.6 μg/L. Chlorophyll *a* concentrations measured in Pleasant Lake exceed the median value observed in Indiana lakes. In fact, concentrations like those observed in Pleasant Lake are typically attributed to highly productive or hypereutrophic lakes. Additionally, blue-green algae, a nuisance alga typically characteristic of hypereutrophic lakes, dominated the Pleasant Lake algal community during the 1990 and 1995 assessments. However, the plankton community was not dominated by blue-green algae during the 1999 and 2004 assessments.

Figure 47 displays the temperature profiles recorded during IDNR fisheries surveys and Indiana Clean Lakes Program (CLP) assessments. All of the temperature profiles show that Pleasant Lake was typically stratified at the time of sampling although some what weakly stratified in some cases. Additionally, these profiles indicate a moderately well to well developed hypolimnion during the assessments as is typical of most Indiana lakes during the summer months.

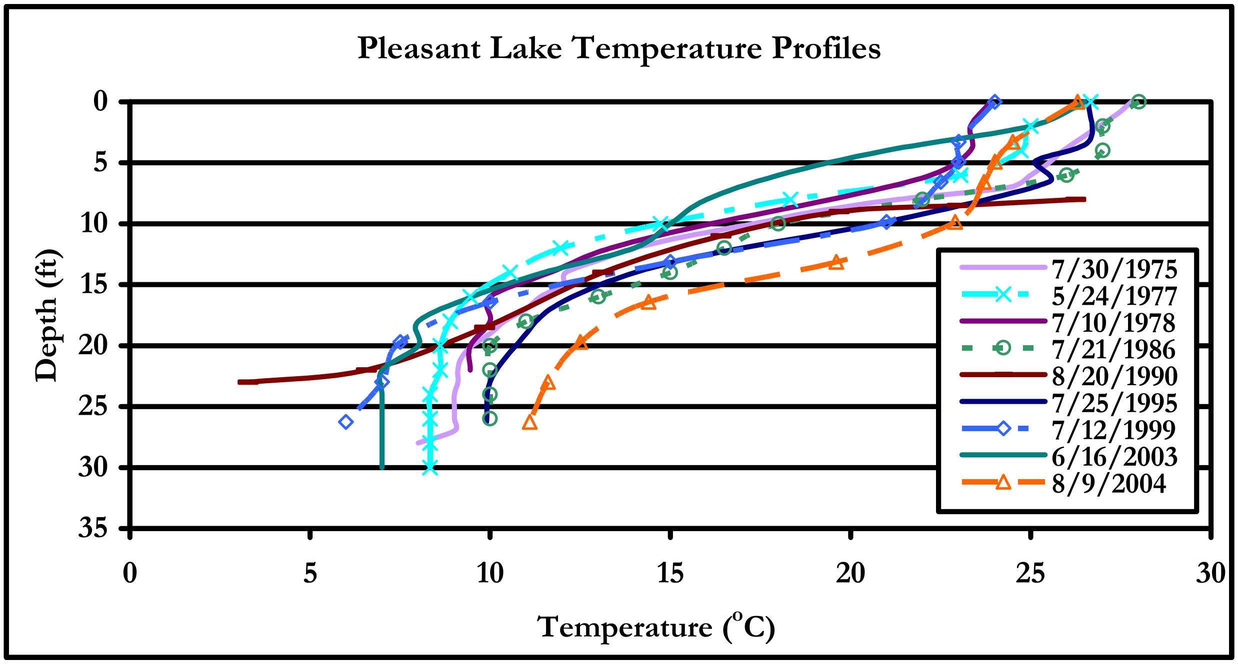

Figure 47. Historical temperature profiles for Pleasant Lake.
Source: IDEM, 1986; Armstrong, 1978; Robertson, 1979, 1987; CLP, 1990, 1995, 1999, and 2004; Price, 2004a.

Much of the data presented above suggest that Pleasant Lake is relatively productive. The historical dissolved oxygen results lend further evidence to this suggestion (Figure 48). Dissolved oxygen profiles indicate that during the 1970s and 1980s the lake was typically anoxic below 5 feet (1.5 m). Dissolved oxygen levels improved since this time as indicated by the 1990, 1995, 1999, and 2004 assessments. During the 1990 to 2004 assessments, Pleasant Lake contained sufficient dissolved oxygen to support aquatic biota to a depth of 12 feet (3.6 m). Despite the improvement, dissolved oxygen levels present throughout the water column limit the availability of habitat for the lake's inhabitants and increase the potential for nutrient release from the lake's bottom sediments as only 40% of Pleasant Lake's water column contains sufficient dissolved oxygen.

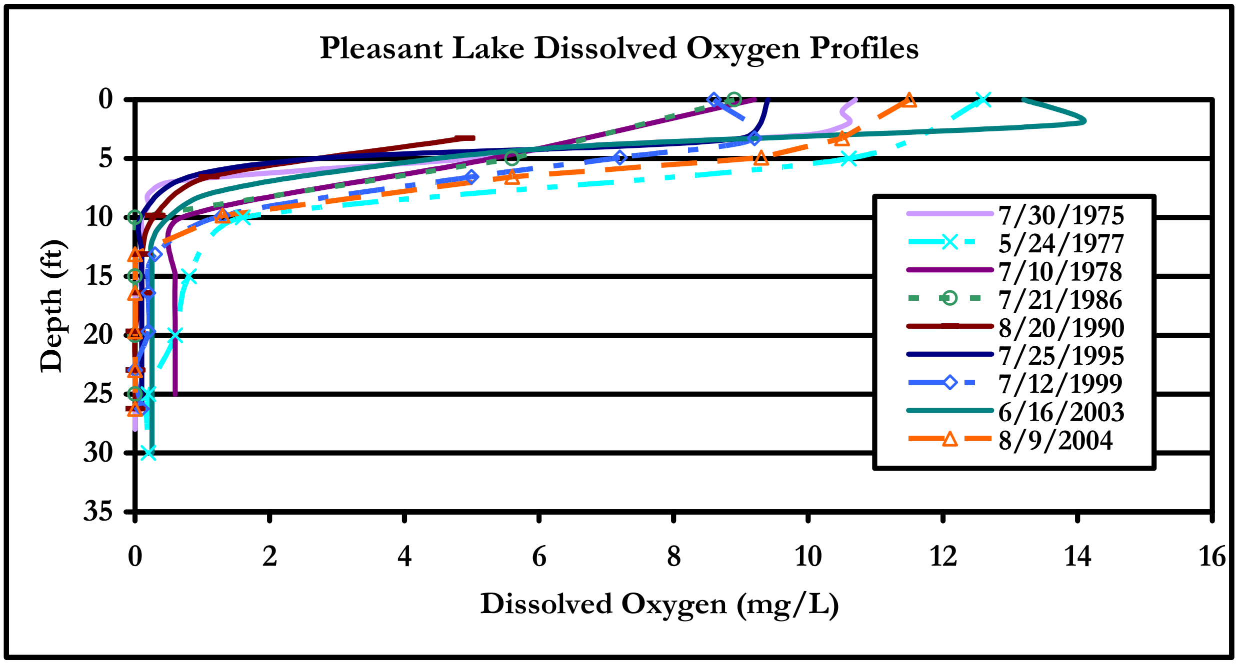

Figure 48. Historical dissolved oxygen profiles for Pleasant Lake.
Source: IDEM, 1986; Armstrong, 1978; Robertson, 1979, 1987; CLP, 1990, 1995, 1999, and 2004; Price, 2004a.

Despite possessing an adequate percentage of the water column that contains sufficient dissolved oxygen for aquatic biota, dissolved oxygen levels were still quite low throughout Pleasant Lake. The apparent lack of dissolved oxygen is a problem for the lake's inhabitants. Fish and other aquatic organisms require oxygen to live. The lack of oxygen below 5 to 12 feet (1.5 to 3.6 m) reduces the amount of habitat available to fish. Respiration by aquatic fauna and decomposition of organic matter likely depleted the dissolved oxygen supply in the lake's deeper water. The lake's elevated hypolimnetic ammonia-nitrogen concentrations present during the 1990, 1995, and 1999 assessments suggest that decomposition typically occurs in the lake's hypolimnion (Tables 33 through 36).

The lack of oxygen in Pleasant Lake's hypolimnion also affects the lake's chemistry. While mean total phosphorus concentrations are variable for the four years displayed in Tables 33 through 36, a more detailed evaluation shows that hypolimnetic total phosphorus concentrations are often higher than epilimnetic total phosphorus concentrations. Under anoxic conditions, like those present in Pleasant Lake, the iron in iron phosphate, a common precipitate in lake sediments, is reduced, and the phosphate ion is released into the water column. This phosphate ion is readily available to algae, and can therefore spur algal growth. Further review of historical phosphorus data indicates that in 1990 and 1995 much of the total phosphorus was in the dissolved form of phosphorus (SRP). This indicates that Pleasant Lake was releasing phosphorus from its bottom sediments. Additionally, Pleasant Lake exhibited higher hypolimnetic ammonia concentrations than those observed in the lake's epilimnion during the 1990, 1995, and 1999 assessments, suggesting decomposition of organic matter was occurring in the lake's bottom waters. Overall, this data suggest that Pleasant Lake can generally be described as a eutrophic to hypereutrophic lake during the 1990, 1995, 1999, and 2004 assessments.

Table 33. Historical water quality characteristics of Pleasant Lake, August 20, 1990.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
Secchi Depth Transparency	0.8 m	-	6
Light Transmission at 3 ft.	5%	-	4
Total Phosphorus	0.097 mg/L	0.106 mg/L	3
Soluble Reactive Phosphorus	0.010 mg/L	0.035 mg/L	0
Nitrate-Nitrogen	1.276 mg/L	1.287 mg/L	3
Ammonia-Nitrogen	0.120 mg/L	0.323 mg/L	0
Organic Nitrogen	2.533 mg/L	2.571 mg/L	4
Oxygen Saturation at 5 ft.	34%	-	0
Percent Water Column Oxic	38%	-	3
Plankton Density	1,720/L	-	0
Blue-Green Dominance	51%	-	10
		TSI Score	**33**

Table 34. Historical water quality characteristics of Pleasant Lake, July 25, 1995.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.2	6.8	-
Alkalinity	119 mg/L	119 mg/L	-
Conductivity	310 μmhos	250 μmhos	-
Secchi Depth Transparency	0.9 m	-	6
Light Transmission at 3 ft.	6%	-	4
1% Light Level	4.5 ft	-	-
Total Phosphorus	0.099 mg/L	0.446 mg/L	4
Soluble Reactive Phosphorus	0.005 mg/L	0.345 mg/L	4
Nitrate-Nitrogen	0.022 mg/L	0.022 mg/L	0
Ammonia-Nitrogen	0.018 mg/L	1.363 mg/L	3
Organic Nitrogen	1.798 mg/L	2.874 mg/L	4
Oxygen Saturation at 5 ft.	35%	-	0
Percent Water Column Oxic	25%	-	4
Plankton Density	75,987/L	-	10
Blue-Green Dominance	68%	-	10
Chlorophyll *a*	61.9 μg/L	-	-
		TSI Score	**49**

Table 35. Historical water quality characteristics of Pleasant Lake, July 12, 1999.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	7.5	6.6	-
Alkalinity	88 mg/L	105.5 mg/L	-
Conductivity	323 μmhos	250 μmhos	-
Secchi Depth Transparency	0.7 m	-	6
Light Transmission at 3 ft.	11%	-	4
1% Light Level	6 ft	-	-
Total Phosphorus	0.099 mg/L	0.195 mg/L	3
Soluble Reactive Phosphorus	0.010 mg/L	0.055 mg/L	1
Nitrate-Nitrogen	0.426 mg/L	0.401 mg/L	2
Ammonia-Nitrogen	0.018 mg/L	0.855 mg/L	2
Organic Nitrogen	1.920 mg/L	3.256 mg/L	4
Oxygen Saturation at 5 ft.	84%	-	0
Percent Water Column Oxic	38%	-	3
Plankton Density	2,158/L	-	0
Blue-Green Dominance	21%	-	0
Chlorophyll *a*	20.1 μg/L	-	-
		TSI Score	**25**

Table 36. Historical water quality characteristics of Pleasant Lake, August 9, 2004.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.6	8.5	-
Alkalinity	99 mg/L	99.5 mg/L	-
Conductivity	313 μmhos	309 μmhos	-
Secchi Depth Transparency	0.9 m	-	6
Light Transmission at 3 ft.	25%	-	4
1% Light Level	13 ft	-	-
Total Phosphorus	0.119 mg/L	0.123 mg/L	3
Soluble Reactive Phosphorus	0.038 mg/L	0.050 mg/L	2
Nitrate-Nitrogen	0.013 mg/L	0.013 mg/L	0
Ammonia-Nitrogen	0.018 mg/L	0.020 mg/L	0
Organic Nitrogen	4.485 mg/L	2.681 mg/L	4
Oxygen Saturation at 5 ft.	110%	-	0
Percent Water Column Oxic	38%	-	4
Plankton Density	5,572/L	-	1
Blue-Green Dominance	14.2%	-	0
Chlorophyll *a*	148.6 μg/L	-	-
		TSI Score	**28**

4.5 Lake Water Quality Assessment

4.5.1 Lake Water Quality Assessment Methods

The water sampling and analytical methods used for Pleasant, Fites, and Riddles lakes were consistent with those used in IDEM's Indiana Clean Lakes Program and IDNR's Lake and River Enhancement Program. Water samples were collected and analyzed for various parameters from Pleasant, Fites, and Riddles lakes on July 18, 2005 from the surface waters (***epilimnion***) and from the bottom waters (***hypolimnion***) of the lakes at a location over the deepest water within each lake. These parameters include conductivity, total phosphorus, soluble reactive phosphorus, nitrate-nitrogen, ammonia-nitrogen, total Kjeldahl nitrogen, and organic nitrogen. In addition to these parameters, several other measurements of lake health were recorded. Secchi disk, light transmission, and oxygen saturation are single measurements made in the epilimnion. Chlorophyll *a* was determined only for an epilimnetic sample. Dissolved oxygen and temperature were measured at one-meter intervals from the surface to the bottom. A tow to collect plankton was made from the 1% light level depth up to the water surface. Conductivity, temperature, and dissolved oxygen were measured *in situ* with an YSI Model 85 meter.

All lake samples were placed in the appropriate bottle (with preservative if needed) and stored in an ice chest until analysis at SPEA's laboratory in Bloomington. SRP samples were filtered in the field through a Whatman GF-C filter.

All sampling techniques and laboratory analytical methods were performed in accordance with procedures in *Standard Methods for the Examination of Water and Wastewater*, 20th Edition (APHA, 1998). Plankton counts were made using a standard Sedgewick-Rafter counting cell. Fifteen fields per cell were counted. Plankton identifications were made according to: Ward and Whipple (1959), Prescott (1982), Whitford and Schumacher (1984), and Wehr and Sheath (2003).

The following is a brief description of the parameters analyzed during the lake sampling efforts:

Temperature. Temperature can determine the form, solubility, and toxicity of a broad range of aqueous compounds. For example, water temperature affects the amount of oxygen dissolved in the water column. Likewise, life associated with the aquatic environment in any location has its species composition and activity regulated by water temperature. Since essentially all aquatic organisms are 'cold-blooded' the temperature of the water regulates their metabolism and ability to survive and reproduce effectively (USEPA, 1976). The Indiana Administrative Code (327 IAC 2-1-6) sets maximum temperature limits to protect aquatic life for Indiana waters. For example, temperatures during the summer months should not exceed 90 °F (32.2 °C).

Dissolved Oxygen (DO). DO is the dissolved gaseous form of oxygen. It is essential for respiration of fish and other aquatic organisms. Fish need at least 3-5 mg/L of DO Coldwater fish such as trout generally require higher concentrations of DO than warmwater fish such as bass or bluegill. The IAC sets minimum DO concentrations at 4 mg/L for warmwater fish, but all waters must have a daily average of 5 mg/L. DO enters water by diffusion from the atmosphere and as a byproduct of photosynthesis by algae and plants. Excessive algae growth can over-saturate (greater than 100% saturation) the water with DO. Conversely, dissolved oxygen is consumed by respiration of aquatic organisms, such as fish, and during bacterial decomposition of plant and animal matter.

Conductivity. Conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions: on their total concentration, mobility, and valence (APHA, 1998). Rather than setting a conductivity standard, the Indiana Administrative Code sets a standard for dissolved solids (750 mg/L). Multiplying a dissolved solids concentration by a conversion factor of 0.55 to 0.75 µmhos per mg/L of dissolved solids roughly converts a dissolved solids concentration to specific conductance (Allan, 1995). Thus, converting the IAC dissolved solids concentration standard to specific conductance by multiplying 750 mg/L by 0.55 to 0.75 µmhos per mg/L yields a specific conductance range of approximately 1000 to 1360 □ mhos. This report presents conductivity measurements at each site in µmhos.

Nutrients. Limnologists measure nutrients to predict the amount of algae growth and/or rooted plant (macrophyte) growth that is possible in a lake or stream. Algae and rooted plants are a natural and necessary part of aquatic ecosystems. Both will always occur in a healthy lake or stream. Complete elimination of algae and/or rooted plants is neither desirable nor even possible and should, therefore, never be the goal in managing a lake or stream. Algae and rooted plant growth can, however, reach nuisance levels and interfere with the aesthetic and recreational uses of a lake or stream. Limnologists commonly measure nutrient concentrations in aquatic ecosystem evaluations to determine the potential for such nuisance growth.

Like terrestrial plants, algae and rooted aquatic plants rely primarily on phosphorus and nitrogen for growth. Aquatic plants receive these nutrients from fertilizers, human and animal waste, atmospheric deposition in rainwater, and yard waste or other organic material that reaches the lake or stream. Nitrogen can also diffuse from the air into the water. This nitrogen is then "fixed" by certain algae species into a usable, "edible" form of nitrogen. Because of this readily available source of nitrogen (the air), phosphorus is usually the "limiting nutrient" in aquatic ecosystems. This means that it is actually the amount of phosphorus that controls plant growth in a lake or stream.

Phosphorus and nitrogen have several forms in water. The two common phosphorus forms are **soluble reactive phosphorus (SRP)** and **total phosphorus (TP)**. SRP is the dissolved form of phosphorus. It is the form that is "usable" by algae. Algae cannot directly digest and use particulate phosphorus. Total phosphorus is a measure of both dissolved and particulate forms of phosphorus. The most commonly measured nitrogen forms are **nitrate-nitrogen (NO_3)**, **ammonium-nitrogen (NH_4^+)**, and **total Kjeldahl nitrogen (TKN)**. Nitrate is a dissolved form of nitrogen that is commonly found in the upper layers of a lake or anywhere that oxygen is readily available. In contrast, ammonium-nitrogen is generally found where oxygen is lacking. ***Anoxia***, or a lack of oxygen, is common in the lower layers of a lake. Ammonium is a byproduct of decomposition generated by bacteria as they decompose organic material. Like SRP, ammonium is a dissolved form of nitrogen and the one utilized by algae for growth. The TKN measurement parallels the TP measurement to some extent. TKN is a measure of the **total organic nitrogen** (particulate) and ammonium-nitrogen in the water sample.

While the United States Environmental Protection Agency (USEPA) has established some nutrient standards for drinking water safety, it has not established similar nutrient standards for protecting the biological integrity of a lake. (The USEPA, in conjunction with the States, is currently working on developing these standards.) The USEPA has issued recommendations for numeric nutrient criteria for lakes (USEPA, 2000a). While these are not part of the Indiana Administrative Code, they serve as potential target conditions for which watershed managers might aim. Other researchers have suggested thresholds for several nutrients in lake ecosystems as well (Carlson, 1977;

Vollenweider, 1975). Lastly, the Indiana Administrative Code (IAC) requires that all waters of the state have a nitrate concentration of less than 10 mg/L, which is the drinking water standard for the state.

With respect to lakes, limnologists have determined the existence of certain thresholds for nutrients above which changes in the lake's biological integrity can be expected. For example, Correll (1998) found that soluble reactive phosphorus concentrations of 0.005 mg/L are enough to maintain eutrophic or highly productive conditions in lake systems. For total phosphorus concentrations, 0.03 mg/L (0.03 ppm – parts per million or 30 ppb – parts per billion) is the generally accepted threshold. Total phosphorus concentrations above this level can promote nuisance algae blooms in lakes. The USEPA's recommended nutrient criterion for total phosphorus is fairly low, 37.5 μg/L (USEPA, 2000a). This is an unrealistic target for many Indiana lakes in this area as the suggested target is lower than the average (66 μg/L) for the ecoregion in which Pleasant and Riddles Lakes lie (Indiana Clean Lakes Program data files, unpublished). It is unlikely that IDEM will recommend a total phosphorus criterion this low for incorporation in the IAC. Similarly, the USEPA's recommended nutrient criterion for nitrate-nitrogen in lakes is low at 16 μg/L. This is below the detection limit of most laboratories. In general, levels of inorganic nitrogen (which includes nitrate-nitrogen) that exceed 0.3 mg/L may also promote algae blooms in lakes. High levels of nitrate-nitrogen can be lethal to fish. The nitrate LC_{50} is 5 mg/L for logperch, 40 mg/L for carp, and 100 mg/L for white sucker. (Determined by performing a bioassay in the laboratory, the LC_{50} is the concentration of the pollutant being tested, in this case nitrogen, at which 50% of the test population died in the bioassay.) The USEPA's recommended criterion for total Kjeldahl nitrogen in lakes is 0.765 mg/L.

It is important to remember that none of the threshold or recommended concentrations listed above are state standards for water quality. They are presented here to provide a frame of reference for the concentrations found in Dewart Lake. The IAC sets only nitrate-nitrogen and ammonia-nitrogen standards for waterbodies in Indiana. The Indiana Administrative Code requires that all waters of the state have a nitrate-nitrogen concentration of less than 10 mg/L, which is the drinking water standard for the state. The IAC standard for ammonia-nitrogen depends upon the water's pH and temperature, since both can affect ammonia-nitrogen's toxicity. The Dewart Lake samples did not exceed the state standard for either nitrate-nitrogen or ammonia-nitrogen.

Secchi Disk Transparency. This refers to the depth to which the black and white Secchi disk can be seen in the lake water. Water clarity, as determined by a Secchi disk, is affected by two primary factors: algae and suspended particulate matter. Particulates (for example, soil or dead leaves) may be introduced into the water by either runoff from the land or from sediments already on the bottom of the lake. Many processes may introduce sediments from runoff; examples include erosion from construction sites, agricultural land, and riverbanks. Bottom sediments may be resuspended by bottom feeding fish such as carp, or in shallow lakes, by motorboats or strong winds. In general, lakes possessing Secchi disk transparency depths greater than 15 feet (4.5 m) have outstanding clarity. Lakes with Secchi disk transparency depths less than 5 feet (1.5 m) possess poor water clarity (ISPCB, 1976; Carlson, 1977). The USEPA recommended a numeric criterion of 4.6 feet (1.4 m) for Secchi disk depth in lakes (USEPA, 2000a).

Light Transmission. Similar to the Secchi disk transparency, this measurement uses a light meter (photocell) to determine the rate at which light transmission is diminished in the upper portion of the lake's water column. Another important light transmission measurement is determination of the

1% light level. The 1% light level is the water depth to which one percent of the surface light penetrates. This is considered the lower limit of algal growth in lakes. The volume of water above the 1% light level is referred to as the ***photic zone***.

Plankton. Plankton are important members of the aquatic food web. Plankton include the algae (microscopic plants) and the zooplankton (tiny shrimp-like animals that eat algae). Plankton are collected by towing a net with a very fine mesh (63-micron openings = 63/1000 millimeter) up through the lake's water column from the one percent light level to the surface. Of the many different planktonic species present in the water, the blue-green algae are of particular interest. Blue-green algae are those that most often form nuisance blooms and their dominance in lakes may indicate poor water conditions.

Chlorophyll *a*. The plant pigments in algae consist of the chlorophylls (green color) and carotenoids (yellow color). Chlorophyll *a* is by far the most dominant chlorophyll pigment and occurs in great abundance. Thus, chlorophyll *a* is often used as a direct estimate of algal biomass. In general, chlorophyll *a* concentrations below 2 μg/L are considered low, while those exceeding 10 μg/L are considered high and indicative of poorer water quality. The USEPA recommended a numeric criterion of 8.6 μg/L as a target concentration for lakes in Aggregate Nutrient Ecoregion VI (USEPA, 2000a). The recommended nutrient criterion is relatively high and represents data from only 224 lakes throughout the entire Aggregate Nutrient Ecoregion. The 25th percentile (2.6 μg/L) for the ecoregion in which Pleasant and Riddles Lakes lie (Indiana Clean Lakes Program data files, unpublished) or Vollenweider's median concentration measured in mesotrophic lakes (4.7 μg/L) likely provide better targets for these lakes.

4.5.2 Riddles Lake Water Quality Assessment Results

Results from the Riddles Lake water characteristics assessment are included in Table 37 and Figure 49. The temperature profile for Riddles Lake shows that the lake was weakly stratified at the time of sampling (Figure 49). Temperature steadily decreased with lake depth from the water surface to the lake bottom. This is likely due to the shallow nature of the lake. This year's temperature profile is very similar to the temperature profiles recorded historically (Figure 44). Due to its shallow nature, wind mixing and boat turbulence likely prevent Riddles Lake from fully stratifying some years. While dissolved oxygen concentrations were high in the first 1.5 feet (0.5 m) of water, oxygen concentrations declined rapidly from the surface to a depth of 6.5 feet (2 m). The water at the surface was 145% saturated; however at depth of 5 feet (1.5 m) below the water's surface the water was only 83% saturated with dissolved oxygen. The lake reached anoxic conditions ([D.O.] < 1.0 mg/L) by the depth of 0.5 feet (2 m). Anoxic conditions at this depth are likely due to biochemical oxygen demand below the epilimnion. Water below 6.5 feet (2 m) did not contain sufficient oxygen content to support fish and other aquatic organisms.

Table 37. Water quality characteristics of Riddles Lake on July 18, 2005.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	8.9	7.6	-
Alkalinity	125 mg/L	166 mg/L	-
Conductivity	418 μmhos	369 μmhos	-
Secchi Depth Transparency	0.7 meters	-	6
Light Transmission at 3 ft.	2.6%	-	4
1% Light Level	3.4 feet	-	-
Total Phosphorus	0.113 mg/L	0.996 mg/L	4
Soluble Reactive Phosphorus	0.010 mg/L*	0.865 mg/L	4
Nitrate-Nitrogen	0.013 mg/L*	0.013 mg/L*	0
Ammonia-Nitrogen	0.030 mg/L	2.648 mg/L	4
Organic Nitrogen	1.996 mg/L	1.878 mg/L	3
Oxygen Saturation at 5ft.	83%	-	0
% Water Column Oxic	28.8%	-	3
Plankton Density	16,903/L	-	3
Blue-Green Dominance	91.9%	-	10
Chlorophyll *a*	44.0 μg/L	-	-
		TSI score	**41**

*Method detection limit

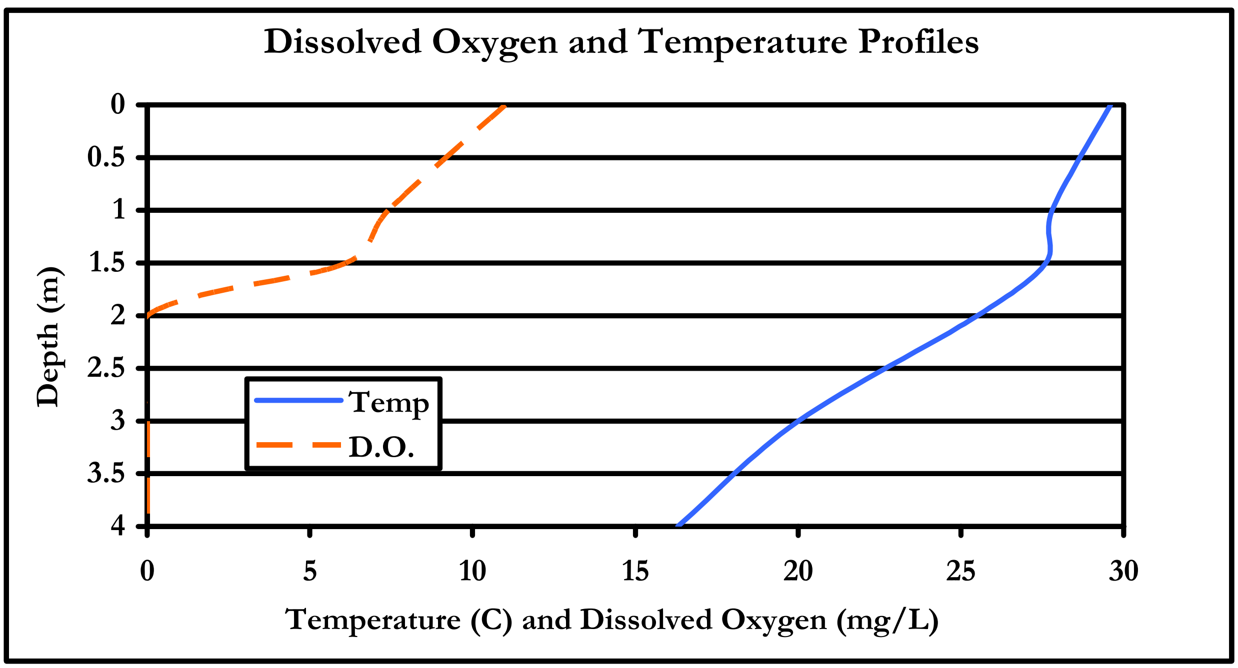

Figure 49. Temperature and dissolved oxygen profiles for Riddles Lake on July 18, 2005.

Water clarity was relatively poor in Riddles Lake. The Secchi disk transparency depth was 2.3 feet (0.7 m) which is less than the USEPA (2000b) target Secchi disk transparency depth of 4.6 feet (1.4 m). Likewise, Riddles Lake's transparency was poorer than the median Secchi disk depth observed in

Indiana lakes (6.9 feet or 2.1 m). Given its relatively poor water clarity, it is not surprising that Riddles Lake exhibited poor light penetration through the water column.

Riddles Lake's rather limited littoral and photic zones are further highlighted by the lake's poor water clarity. In previous sections of this report, Riddles Lake's littoral zone was estimated to be the area of the lake in which water depth was less than three times the lake's Secchi disk transparency depth. While this is a good estimate, by definition, the lake's littoral zone is area of the lake in which water is shallow enough to support plant growth. Limnologists often use the lake's 1% light level to determine the lower limit of sufficient light to support plant photosynthesis, or growth. Thus, by definition, a lake's littoral zone is that area of the lake with water that is shallower than the lake's 1% light level.

Because of the lake's poor water clarity, Riddles Lake's 1% light level is relatively shallow, extending to a depth of 3.4 feet (1.0 m). Using the definition of littoral zone provided above, Riddles Lake's littoral zone is that portion of the lake with water depths less than 6.9 feet (2.1 m). Based on the depth-area curve in Figure 39, this would mean that Riddles Lake's littoral zone is approximately 19 acres (7.9 ha) in size and covers 24% of the lake's surface area. A previous section of this document suggests Riddles Lake's littoral zone is approximately 35 acres (14.2 ha) in size and covers approximately 45% of the lake. (This estimate was based on the lake's Secchi disk transparency.) The estimate of the lake's littoral zone using the Secchi disk transparency is more consistent with actual field conditions. Rooted plants cover an estimated 29 acres (11.7 ha) of the lake as observed during the rooted plant survey. Regardless of which estimate is used, Riddles Lake's littoral zone is limited.

The lake's 1% light level also defines the lake's *photic zone*. A lake's *photic zone* is the volume of water with sufficient light to support algae growth. Based on Riddles Lake's depth-volume curve (Figure 40), approximately 375 acre-feet of Riddles Lake (60% of total lake volume) lies above the 3.4-foot (1.0-m) 1% light level. This <u>volume</u>, referred to as the ***photic zone***, represents the amount of water with sufficient light. This volume constitutes the lake's photic zone.

Conductivity, alkalinity, and pH values were all within normal ranges for Indiana. The relatively high alkalinity values of 125 mg/L and 166 mg/L, for the epilimnion and hypolimnion, respectively, indicate that Riddles Lake is a well buffered system. As is typical, Riddles Lake's epilimnetic pH was higher than its hypolimnetic pH. As was historically observed within Riddles Lake (Table 29), the epilimnetic pH was relatively high. A high epilimnetic pH may indicate the presence of photosynthesizing algae. During the process of photosynthesis, algae remove carbon dioxide, a weak acid, from the water column, thereby increasing the water's pH. The lack of photosynthesis in the hypolimnion and the liberation of carbon dioxide by respiring bacteria keep pH levels lower in the hypolimnion.

Phosphorus and nitrogen are the primary plant nutrients in lakes and therefore are measured in lake water quality analyses. In the summer, Indiana lakes typically possess lower nutrient concentrations in their epilimnia compared to nutrient concentrations present in their hypolimnia. Algae in the lake's epilimnion often utilize a large portion of the readily available nutrients for growth. When the algae die and settle to the bottom sediments, nutrients are relocated to the hypolimnion. Higher concentrations of phosphorus in the hypolimnion may also result from chemical processes occurring at the sediment-water interface.

Mean soluble phosphorus and total phosphorus concentrations are higher in Riddles Lake than the median for 456 Indiana lakes measured from 1994 to 2004 in the Indiana Clean Lakes Program (CLP, 2004). This is primarily due to higher concentrations of soluble reactive phosphorus (0.865 mg/L) and total phosphorus (0.996 mg/L) in the hypolimnion. Higher phosphorus concentrations within the hypolimnion are usually associated with nutrient release from the sediments under anoxic conditions. Sedimentation of particulates and plankton also provide a source of phosphorus to the hypolimnion. The total phosphorus concentration in the epilimnion (0.113 mg/L) implies that an appreciable amount of phosphorus resides in biomass and particles at shallower depths, as well.

Total and soluble reactive phosphorus concentrations were generally high in Riddles Lake. The total phosphorus concentration in Riddles Lake's epilimnion was relatively high for Indiana lakes. The total phosphorus concentration of 0.118 mg/L was more than three times the 0.03 mg/L concentration threshold that is considered high enough to support eutrophic conditions (Wetzel, 2001). However, the total phosphorus concentration was considerably higher in the hypolimnion, measuring 0.996 mg/L. The mean total phosphorus concentration (0.554 mg/L) exceeded the USEPA target total phosphorus concentration of 0.038 mg/L (USEPA, 2000a) by nearly a factor of 30. However, the soluble reactive phosphorus concentration in the epilimnion was also relatively low measuring below the detection level (0.010 mg/L). This is typical in lakes since SRP is readily consumed by algae in the lake's epilimnion. The SRP concentration in Riddles Lake's hypolimnion was high measuring 0.865 mg/L. The data indicate that most of the total phosphorus concentration in the hypolimnion consists of soluble reactive phosphorus. This dominance of the dissolved form of phosphorus coupled with the lack of oxygen in the deep waters over the bottom sediments suggests that dissolved phosphorus is being released from the lake's bottom sediments. This is called ***internal phosphorus loading*** and can be a significant additional source of phosphorus in some lakes. (The extent of internal phosphorus loading will be examined using a model later in this report.) Comparing the 2005 results to historic assessments, phosphorus concentrations appear to have increased since the 1999 assessment and are nearly five times the concentration measured during the initial assessment of the lake in 1964.

Nitrate-nitrogen concentrations were at or below the detection limit in Riddles Lake's epilimnion and hypolimnion. Nitrate-nitrogen concentrations were below the USEPA target concentration of 0.016 mg/L (USEPA, 2000a). Nitrate-nitrogen is reduced to ammonia when oxygen is low. Riddles Lake's hypolimnion lacks oxygen; therefore, any nitrate-nitrogen reaching the lake's lower waters is quickly converted to ammonia. Ammonia is also a by-product of bacterial decomposition. The decomposition of organic matter likely occurring in Riddles Lake's hypolimnion contributes to the relatively high ammonia concentration observed in Riddles Lake's hypolimnion (2.648 mg/L) compared to the epilimnetic concentration (0.030 mg/L). Like the total phosphorus concentration, ammonia concentrations, particularly the hypolimnetic concentration, has more than doubled since 1995 suggesting that water quality declined from that observed ten years ago. Organic nitrogen was distributed more evenly throughout the water column than ammonia-nitrogen. The mean concentration measured 1.937 mg/L. This likely represents a reservoir of nitrogen in the lake. As more decomposition occurs, this organic nitrogen will be converted to ammonia, thereby increasing ammonia-nitrogen concentrations throughout the water column.

The plankton collected in a sample from Riddles Lake are enumerated in Table 38. The blue-green algae *Aphanizomenon* was the dominant genus in the sample, accounting for 52% of the total numbers. Other blue-green algae were also abundant, contributing to a blue-green dominance of 91%. Blue-greens are usually associated with degraded water quality. Blue-green algae are less desirable in lakes because they: 1) may form extremely dense nuisance blooms; 2) may cause taste and odor problems; and 3) are unpalatable as food for many zooplankton grazers. Blue-green dominance contributed considerably to the high Indiana TSI score for 2005 although the total density of all plankton was low (16,903 organisms/L) and contributed only 3 eutrophy points. Small single-cell or nanoplankton can easily pass through the standard 63-micron sampling net utilized for the standard sampling. It is possible that this might have happened here.

Table 38. Plankton community represented in sample Riddles Lake on July 18, 2005.

Species	**Abundance (#/L)**	**Percentage of Plankton Population**
Blue-Green Algae (Cyanophyta)		
Aphanizomenon	8,899	52.6%
Anabaena	3,350	19.8%
Aphanocapsa	2,303	13.6%
Microcystis	558	3.3%
Filamentous blue-green (unknown)	209	1.2%
Merismopedia	174	1.0%
Coelosphaerium	35	0.2%
Green Algae (Chlorophyta)		
Ulothrix	593	3.5%
Diatoms (Bacillariophyta)		
Synedra	140	0.8%
Rotifers		
Keratella	70	0.4%
Kellicottia	35	0.2%
Filinia	35	0.2%
Other Algae		
Ceratium	419	2.5%
Peridinium	35	0.2%
Zooplankton		
Nauplius	39	0.2%
Calanoid Copepod	6	<0.1%
Cyclopoid Copepod	4	<0.1%
Total Plankton Population	**16,904**	**100%**

4.5.3 Pleasant Lake Water Quality Assessment Results

Results from the Pleasant Lake water characteristics assessment are included in Table 39 and Figure 50.

Table 39. Water quality characteristics of Pleasant Lake on July 18, 2005.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	9.0	8.1	-
Alkalinity	112 mg/L	120 mg/L	-
Conductivity	426 µmhos	288 µmhos	-
Secchi Depth Transparency	0.7 meters	-	6
Light Transmission at 3 ft.	3.2%	-	4
1% Light Level	4.5 feet	-	-
Total Phosphorus	0.094 mg/L	0.714 mg/L	4
Soluble Reactive Phosphorus	0.011 mg/L	0.560 mg/L	4
Nitrate-Nitrogen	0.013 mg/L*	0.013 mg/L*	0
Ammonia-Nitrogen	0.052 mg/L	0.811 mg/L	2
Organic Nitrogen	2.054 mg/L	1.520 mg/L	3
Oxygen Saturation at 5 ft.	104%	-	0
% Water Column Oxic	23.5%	-	4
Plankton Density	43,036/L		5
Blue-Green Dominance	98.6%	-	10
Chlorophyll *a*	37.1 µg/L	-	-
		TSI score	**52**

*Method detection limit

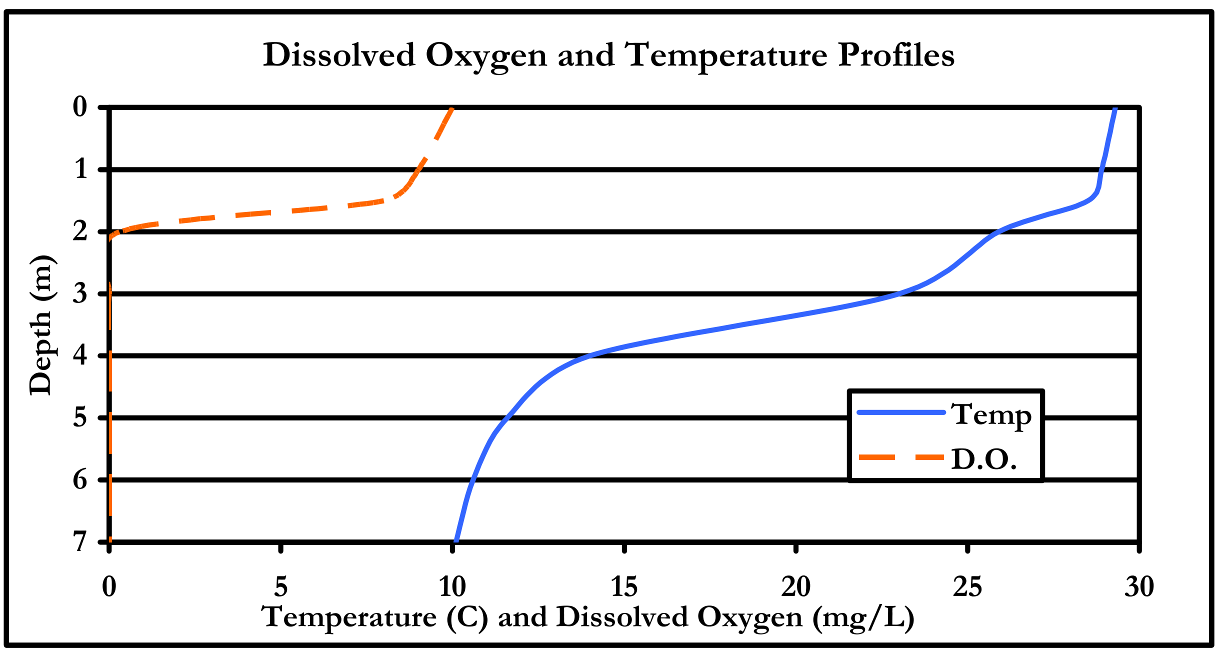

Figure 50. Temperature and dissolved oxygen profiles for Pleasant Lake on July 18, 2005.

Temperature and oxygen profiles for Pleasant Lake show that the lake was stratified at the time of sampling (Figure 50). During thermal stratification, the bottom waters (*hypolimnion*) of the lake are isolated from the well-mixed *epilimnion* (surface waters) by temperature-induced density differences. The boundary between these two zones, where temperature changes most rapidly with depth, is called the *metalimnion*. At the time of sampling, the epilimnion was confined to the upper 4.9 feet (1.5 m) of water. The decline in temperature between the depths of 4.9 and 13.1 feet (1.5 and 4 m) defines the metalimnion or transition zone. The hypolimnion occupied water deeper than 13.1 feet (4 m).

The dissolved oxygen profile mirrors the temperature profile and is generally consistent with historical dissolved oxygen profiles for the lake (Figure 48). The lake was supersaturated in the *epilimnion* (surface waters) maintaining a saturation of 130% at 5 feet (1.5 m). The oxygen concentration decreases rapidly within the epilimnion to a depth of 6.6 feet (2 m), at which there is no dissolved oxygen remaining in the lake. This is likely due to biological oxygen demand (BOD) from excess organic detritus in the lake's deeper waters. Respiration by aquatic fauna and decomposition of organic matter likely depleted the oxygen supply in the lake's deeper waters. Water below 6.6 feet (4 m) did not contain sufficient dissolved oxygen to support fish and other aquatic organisms. The lack of oxygen at the lake-sediment interface created conditions conducive to the release of phosphorus from the lake's sediments. Only 23.5% of the lake's water column was oxic, limiting the amount of habitat available for aquatic fauna.

Water clarity was relatively poor in Pleasant Lake. The Secchi disk transparency depth was 2.3 feet (0.7 m) which is roughly less than half the USEPA (2000b) target Secchi disk transparency depth of 4.6 feet (1.4 m). Likewise, Pleasant Lake's transparency was poorer than the median Secchi disk depth observed in Indiana lakes (6.9 feet or 2.1 m). Given its relatively poor water clarity, it is not surprising that Pleasant Lake exhibited poor light penetration through the water column. The 1% light level, which limnologists use to determine the lower limit where photosynthesis can occur, extended to 4.5 ft (1.4 m). This area, referred to as the *photic zone*, represents the amount of water with sufficient light to support algae growth.

Total and soluble reactive phosphorus concentrations were generally high in Pleasant Lake. The total phosphorus concentration in Pleasant Lake's epilimnion was relatively high for Indiana lakes. Likewise, the total phosphorus concentration of 0.094 mg/L exceeded the 0.03 mg/L concentration threshold that is considered high enough to support eutrophic conditions (Wetzel, 2001). Furthermore, the total phosphorus concentration was considerably higher in the hypolimnion measuring 0.714 mg/L. Therefore, the mean total phosphorus concentration (0.404 mg/L) exceeded the USEPA target total phosphorus concentration of 0.038 mg/L (USEPA, 2000a) by nearly a factor of 20. Conversely, the soluble reactive phosphorus concentration in the epilimnion was relatively low measuring 0.011 mg/L. This is typical in lakes since SRP is readily consumed by algae in the lake's epilimnion. The SRP concentration in Pleasant Lake's hypolimnion was high measuring 0.560 mg/L. The data indicate that most of the total phosphorus concentration in the hypolimnion consists of soluble reactive phosphorus. This dominance of the dissolved form of phosphorus coupled with the lack of oxygen in the deep waters over the bottom sediments suggests that dissolved phosphorus is being released from the lake's bottom sediments. This is called ***internal phosphorus loading*** and can be a significant additional source of phosphorus in some lakes. (The extent of internal phosphorus loading will be examined using a model later in this report.) Comparing the 2005 results to historic assessments, phosphorus concentrations appear to have increased since the 2004 assessment and are nearly four times the concentration measured during the initial assessment of the lake in 1975.

Nitrate-nitrogen concentrations were low throughout the water column. Nitrate-nitrogen concentrations were at or below the detection limit in both the epilimnion and hypolimnion of Pleasant Lake. Additionally, nitrate-nitrogen concentrations were below the USEPA target concentration of 0.016 mg/L throughout the water column (USEPA, 2000a). Nitrate-nitrogen is reduced to ammonia when oxygen is low. Pleasant Lake's hypolimnion lacks oxygen; therefore, any nitrate-nitrogen reaching the lake's lower waters is quickly converted to ammonia. Ammonia is also a by-product of bacterial decomposition. The decomposition of organic matter likely occurring in Pleasant Lake's hypolimnion contributes to the relatively high ammonia concentration observed in Pleasant Lake's hypolimnion (0.811 mg/L) compared to the epilimnetic concentration (0.052 mg/L). Thus, the high hypolimnetic ammonia concentrations relate to the presence of high biochemical oxygen demand (BOD) and low dissolved oxygen. Unlike the total phosphorus concentration, ammonia concentrations, particularly the hypolimnetic concentration, has widely fluctuated since the 1990 assessment suggesting that ammonia-nitrogen concentrations vary over time and do not adequately represent a cut and dried determination of Pleasant Lake's water quality.

The pH values of 9.0 and 8.1 measured in the epilimnion and hypolimnion, respectively were within the normal range for Indiana lakes and typical of most fresh waters (Kalff, 2002). However, the epilimnetic pH was relatively high. A high epilimnetic pH may indicate the presence of photosynthesizing algae. During the process of photosynthesis, algae remove carbon dioxide, a weak acid, from the water column, thereby increasing the water's pH. The lack of photosynthesis in the hypolimnion and the liberation of carbon dioxide by respiring bacteria keep pH levels lower in the hypolimnion. The alkalinity values, a measure of buffering capacity, of 111.5 mg/L and 120 mg/L for the epilimnion and hypolimnion, respectively indicate that Pleasant Lake is well buffered against large changes in pH. Conductivity values, a measure of dissolved ions, were within the normal range for Indiana lakes.

Plankton enumerated from the sample collected from Pleasant Lake are shown in Table 40. Overall plankton density was relatively high measuring 43,036 organisms/L. The lake's chlorophyll *a* concentration was 37.1 μg/L, which is nearly three times the median chlorophyll *a* concentration measured in Indiana lakes (12.9 μg/L). Pleasant Lake's chlorophyll *a* concentration is also much higher (an order of magnitude or more than ten times higher) than the target USEPA chlorophyll *a* concentration of 3.7 μg/L (USEPA, 2000a). Pleasant Lake's chlorophyll *a* concentration also exceeds Vollenweider's median chlorophyll *a* concentration measured in eutrophic lakes (14.3 μg/L; Vollenweider, 1975). *Aphanizomenon*, a blue-green algae, was the dominant algae found in Pleasant Lake accounting for approximately 87% of the plankton density. This particular blue-green algae as well as other blue-green species accounted for 99% of the plankton community. Blue-greens are usually associated with degraded water quality. Blue-green algae are less desirable in lakes because they: 1) may form extremely dense nuisance blooms; 2) may cause taste and odor problems; and 3) are unpalatable as food for many zooplankton grazers. Blue-green dominance contributed considerably to the high Indiana TSI score for 2005 (a total of 10 points). However, the total density of plankton (43,036 organisms/L) contributed only 5 of 25 total eutrophy points.

Table 40. The plankton sample representing the species assemblage in Pleasant Lake on July 18, 2005.

Species	Abundance (#/L)	Percentage of Plankton Population
Blue-Green Algae (Cyanophyta)		
Aphanizomenon	37469	87.1%
Anabaenopsis	1349	3.1%
Filamentous blue-green (unknown)	1349	3.1%
Aphanocapsa	1001	2.3%
Chroococcus	435	1.0%
Merismopedia	392	0.9%
Anabaena	174	0.4%
Microcystis	174	0.4%
Coelosphaerium	87	0.2%
Green Algae (Chlorophyta)		
Staurastrum	44	0.1%
Coccomyxa	44	0.1%
Diatoms (Bacillariophyta)		
Synedra	435	1.0%
Zooplankton		
Nauplius	83	0.2%
Calanoid Copepod	1	<0.1%
Total Number of Plankton	**43,036**	**100%**

4.5.4 Fites Lake Water Quality Assessment Results

Results from the Fites Lake water characteristics assessment are included in Table 41 and Figure 51.

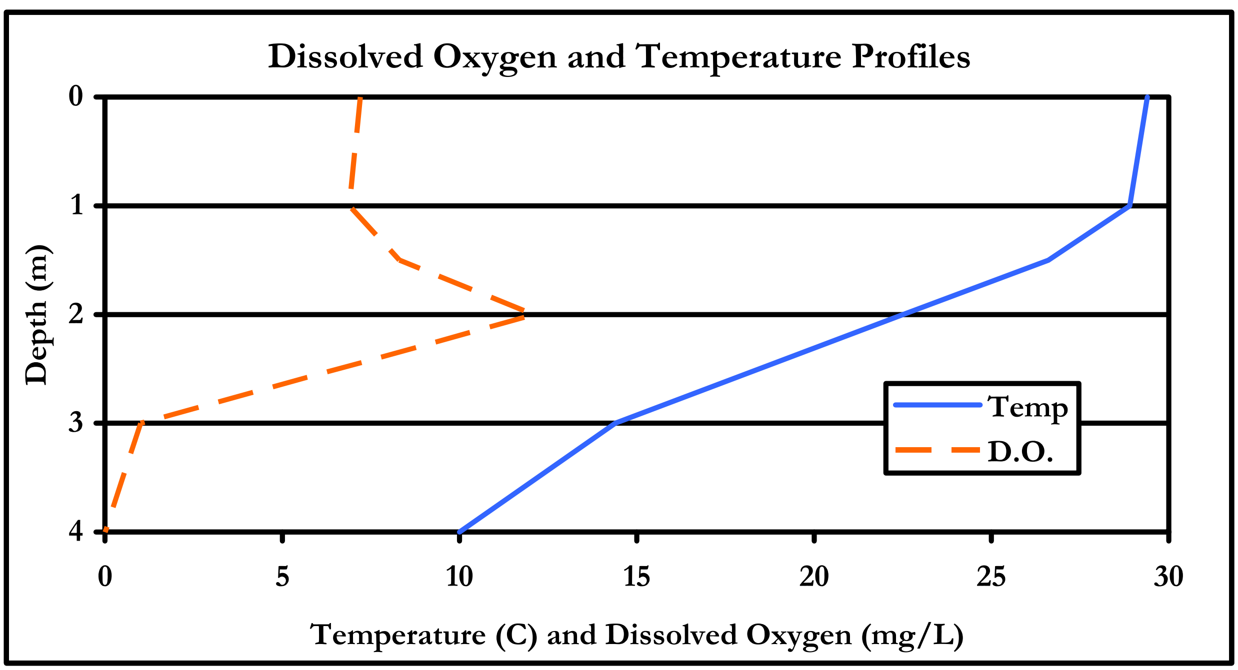

Figure 51. Temperature and dissolved oxygen profiles for Fites Lake on July 18, 2005.

Table 41. Water quality characteristics of Fites Lake on July 18, 2005.

Parameter	Epilimnetic Sample	Hypolimnetic Sample	Indiana TSI Points (based on mean values)
pH	7.5	6.9	-
Alkalinity	18 mg/L	35 mg/L	-
Conductivity	100 μmhos	73 μmhos	-
Secchi Depth Transparency	1.2 meters	-	6
Light Transmission at 3 ft.	8.5%	-	4
1% Light Level	7.2 feet	-	-
Total Phosphorus	0.031 mg/L	0.126 mg/L	3
Soluble Reactive Phosphorus	0.010 mg/L*	0.010 mg/L*	0
Nitrate-Nitrogen	0.013 mg/L*	0.013 mg/L*	0
Ammonia-Nitrogen	0.041 mg/L	0.021 mg/L	0
Organic Nitrogen	1.926 mg/L	2.809 mg/L	4
Oxygen Saturation at 5ft.	103%	-	0
% Water Column Oxic	61.6%	-	2
Plankton Density	17,212/L	-	3
Blue-Green Dominance	94.8 %	-	10
Chlorophyll *a*	8.3 μg/L	-	-
		TSI score	**32**

*Method detection limit

The temperature profile for Fites Lake shows that the lake was weakly stratified at the time of sampling (Figure 51). Temperature steadily decreased with depth from the water surface to the lake bottom. This is likely due to the shallow nature of the lake. Due to its shallow nature, wind mixing likely prevents Fites Lake from fully stratifying. The peak that is present at 6.6 feet (2 m) below the lake's surface represents a *metalimnetic oxygen maximum* and is likely associated with a higher concentrations of phytoplankton at that particular depth layer. A peak like this typically results when the rate of settling plankton slows in the denser waters of the metalimnion. As the plankton at this depth photosynthesize, they release oxygen into the water column, creating a peak in oxygen at that level. The lake reached anoxia ([D.O.] < 1.0 mg/L) around the depth of 9.8 feet (3 m). This is likely due to biochemical oxygen demand in the deeper waters. The lack of oxygen at this depth limits habitat available to support fish and other aquatic organisms.

Water clarity in Fites Lake was relatively good when compared to other lakes in the Pleasant and Riddles Lakes watershed. However, Fites Lake exhibited a Secchi disk transparency depth of 3.9 feet (1.2 m), which is poorer than the target Secchi disk depth of approximately 4.6 feet (1.4 m) recommended by the USEPA (2000b). Fites Lake's transparency was also below the median Secchi disk depth observed in Indiana lakes (6.9 feet or 2.1 m). Light transmission was poor at the time of sampling, with approximately 8.5% of incident light reaching a depth of 3 feet (0.9 m) below the lake's surface. Conversely, the 1% light level, which limnologists use to determine the lower limit where photosynthesis can occur, extended to 7.2 ft (2.2 m). The volume of water that lies above this 7.2-foot 1% light level is referred to as the *photic zone*, or the amount of water with sufficient light to support algae growth.

Nutrient concentrations within Fites Lake are lower than those recorded in either Pleasant or Riddles lakes. SRP and nitrate-nitrogen concentrations were low measuring below the laboratory detection limit in both the epilimnion and the hypolimnion. Ammonia-nitrogen concentrations were also relatively low throughout the water column averaging 0.031 mg/L. Total phosphorus concentrations were low in the epilimnion (0.031 mg/L) and moderately high in the hypolimnion (0.126 mg/L). Because of this, the mean total phosphorus concentration of 0.078 mg/L exceeded the 0.03 mg/L concentration threshold that is considered high enough to support eutrophic conditions (Wetzel, 2001). Furthermore, the mean total phosphorus concentration (0.078 mg/L) was nearly double the USEPA target total phosphorus concentration of 0.038 mg/L (USEPA, 2000a). Elevated phosphorus concentrations within the hypolimnion are usually associated with nutrient release from the sediments under anoxic conditions. Because a majority of the total phosphorus present in the hypolimnion is in particulate form (as evidenced by the low soluble reactive phosphorus concentration present in the hypolimnion), settling of particulates and plankton are likely sources of phosphorus to the hypolimnion. This hypothesis is supported by the relatively high organic nitrogen concentration in the lake's hypolimnion.

The pH values in Fites Lake, pH 7.5 for the epilimnion and pH 6.9 for the hypolimnion, fall within the normal range for Indiana lakes. A pH range from 6.5 to 9.0 appears adequate for the survival of freshwater fish and other aquatic organisms (EPA, 1976). The low alkalinity values of 18 mg/L and 35 mg/L, for the epilimnion and hypolimnion, respectively, indicate that Fites Lake has low buffering capacity. The lake is therefore susceptible to rapid changes in pH.

The plankton groups represented in a sample from Fites Lake are enumerated in Table 42. The blue-green algae *Planktothrix* was the dominant genus, followed by the blue-greens *Aphanizomenon* and *Anabaena*. As a whole, blue-green algae accounted for 94.5% of all plankton. Blue-greens are usually associated with degraded water quality. Blue-green algae are less desirable in lakes because they: 1) may form extremely dense nuisance blooms; 2) may cause taste and odor problems; and 3) are unpalatable as food for many zooplankton grazers. Blue-green algae dominance contributed considerably to the high Indiana TSI score for 2005. The low density of total plankton (17,212 organisms/L) contributed only 3 eutrophy point to the Indiana TSI score.

Table 42. Plankton community represented in sample Fites Lake on July 18, 2005.

Species	Abundance (#/L)	Percentage of Plankton Population
Blue-Green Algae (Cyanophyta)		
Planktothrix	5779	33.6%
Aphanizomenon	3678	21.4%
Anabaena	3449	20.0%
Chroococcus	2127	12.4%
Microcystis	805	4.7%
Filamentous blue-green (unknown)	287	1.7%
Cylindrospermopsis	115	0.7%
Aphanocapsa	57	0.3%
Spirulina	57	0.3%
Green Algae (Chlorophyta)		
Staurastrum	27	0.2%
Other Algae		
Synedra	575	3.3%
Dinobryon	230	1.3%
Zooplankton		
Nauplius	20	0.1%
Daphnia	3	<0.1%
Calanoid Copepod	2	<0.1%
Cyclopoid Copepod	1	<0.1%
Total Number of Plankton	**17,212**	**100%**

4.5.5 Lake Water Quality Assessment Discussion

The interpretation of a comprehensive set of water quality data can be quite complicated. Often, attention is directed at the important plant nutrients (phosphorus and nitrogen) and to water transparency (Secchi disk) since dense algal blooms and poor transparency greatly affect the health and use of lakes. Table 43 presents a comparison of several water quality parameters, particularly nutrient and transparency parameters, among the lakes in the Pleasant and Riddles Lakes watershed.

Table 43. Summary of water quality data for lakes in the Pleasant and Riddles Lakes watershed on July 18, 2005.

Lake	Secchi Disk (ft)	Mean Total P (mg/L)	Mean SRP (mg/L)	Sediment Phosphorus Release[1]	Hypo NH_4 (mg/L)	TN:TP[2]	Chl *a* (µg/L)	Total Plankton (#/L)
Pleasant	2.2	0.404	0.285	50.9	0.811	21.9	37.1	43,036
Fites	3.9	0.079	0.010	1.0	0.021	62.1	8.3	17,212
Riddles	2.2	0.554	0.437	86.6	2.648	17.6	44.0	16,903

[1]Hypolimnetic Soluble Reactive Phosphorus (SRP) concentration/Epilimnetic SRP concentration. For example, Pleasant Lake's hypolimnetic SRP concentration is 21.9 times that in the epilimnion. This difference is strong evidence of substantial internal loading of phosphorus.
[2]TN:TP ratios are calculated based on epilimnetic concentrations.

Secchi disk transparency is a measure of suspended material in the water that interferes with light penetration. Resuspended bottom sediments, soil washed into the lake from watershed runoff, and algae all contribute to poor Secchi disk transparencies. It is expected that the lakes with the lowest

Secchi disk transparencies will have the highest amounts of plankton and chlorophyll *a*. This holds true in the Pleasant and Riddles Lakes watershed lakes. Pleasant Lake possesses the poorest water clarity (2.2 feet or 0.7 m) and also the most dense plankton community (43,036 organisms per liter).

In most lakes throughout Indiana, higher chlorophyll *a* concentrations are typically observed in lakes with higher total phosphorus concentrations (Jones, 1996). At the time of the current water quality sampling, there was a statistically significant relationship between epilimnetic total phosphorus and chlorophyll *a* concentrations (Figure 52). Riddles Lake possessed the highest total phosphorus concentration in its epilimnion and throughout the water column and the highest chlorophyll *a* concentration. Conversely, Fites Lake possessed the lowest epilimnetic and water column total phosphorus concentrations and the lowest chlorophyll *a* concentration. With phosphorus the limiting nutrient in these lakes, we would expect that the lake with the lowest phosphorus concentration would have the lowest algal populations which is true within these three lakes. A total nitrogen to total phosphorus ratio of >7:1 is indicative of phosphorus limitation. This means that if more phosphorus is added to such lakes, additional algal growth should result.

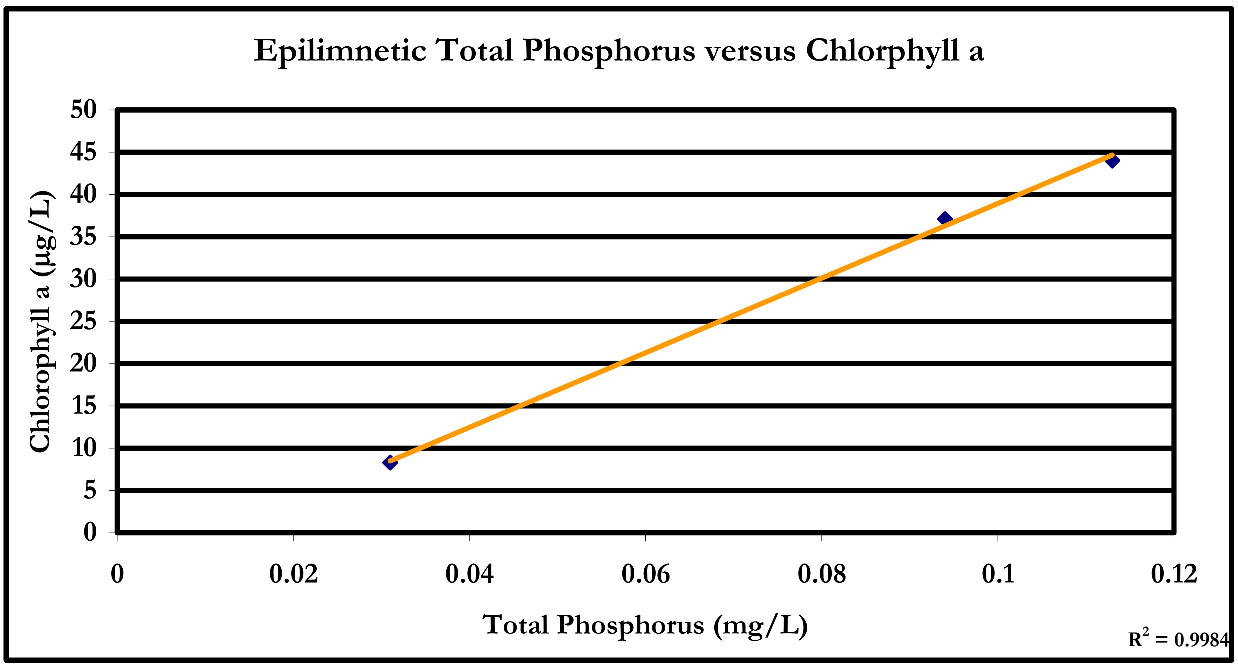

Figure 52. Relationship between epilimnetic total phosphorus and chlorophyll *a* concentrations in Pleasant, Fites, and Riddles lakes. (R^2=0.9984; $p<0.05$)

Pleasant, Fites, and Riddles lakes all contain more phosphorus than is ideal. The potential exists for excessive algal production to occur in these lakes. (Evidence indicates that excessive algal production occurred in Pleasant and Riddles Lakes during the Clean Lakes Program 1995 assessments (Tables 30 and 34).) All three lakes are considered hypereutrophic when evaluated with Carlson's total phosphorus TSI. While conditions visible on the surface of the lakes may not appear overly bad, conditions in the lakes' hypolimnia are of concern. Years of excessive plant and algae production have led to the build-up of decaying organic matter in the sediments of the lakes. As bacteria decompose this material, they consume oxygen and leave the bottom waters anoxic. All of the lakes suffer from periods of anoxia.

In addition to the watershed sources described previously, phosphorus can also be 'released' from lake sediments under chemically reducing conditions present when the lake is *anoxic* (dissolved oxygen concentrations < 1.0 mg/L). The column headed "Sediment Phosphorus Release" provides a comparison of the amount of soluble phosphorus (the form of phosphorus that can be released from the sediments) in the deepwater (hypolimnetic) samples to the surface (epilimnetic) samples. In Fites Lake, the ratio is 1 indicating that no phosphorus release was occurring at the time of our sampling. In the Pleasant Lake the ratio is 50.9, while the ratio for Riddles Lake is 86.6. This indicates that sediment phosphorus release is occurring in both of these lakes. Phosphorus release from the sediments is an additional and important source of phosphorus to lakes that must be addressed along with watershed practices when designing a management plan to reduce nutrient loading to lakes. This *internal loading* of phosphorus is another source of phosphorus to these lakes that can promote excessive algae production.

Pleasant and Riddles lakes also contain relatively high ammonia-nitrogen concentration in their hypolimnia (Table 43). Ammonia is a by-product of bacterial decomposition. When ammonia occurs in high concentrations, it is evidence of high biological oxygen demand. This biological oxygen demand comes from organic waste, such as dead algae and rooted plants, within the sediments, which provides further evidence of excess algae and rooted plant growth in these lakes.

Secchi disk transparency is a measure of suspended material in the water that interferes with light penetration. Resuspended bottom sediments, soil washed into the lake from watershed runoff, and algae all contribute to poor Secchi disk transparencies. Table 43 demonstrates that the lake (Pleasant Lake) with the lowest Secchi disk transparency (2.2 feet or 0.7 m) generally has the highest amounts of plankton density. This does not hold true in Riddles Lake which possesses an equally poor Secchi disk transparency. The reported plankton density does not represent the true density of plankton present in Riddles Lake. It is likely that nanoplankton passes through the plankton net and were therefore not contained within the preserved and counted sample.

To more fully understand the water quality data, limnologists often compare data from the lake in question to standards, if they exist, or to other lakes, or to criteria that most limnologists agree upon. There are no nutrient standards for Indiana lakes, results from Pleasant, Fites, and Riddles lakes are compared below with data from other lakes and with generally accepted criteria.

Comparison with Vollenweider's Data

Results of studies conducted by Richard Vollenweider in the 1970's are often used as guidelines for evaluating concentrations of water quality parameters. His results are given in the Table 44. Vollenweider relates the concentrations of selected water quality parameters to a lake's *trophic state*. The trophic state of a lake refers to its overall level of nutrition or biological productivity. Trophic categories include: ***oligotrophic***, ***mesotrophic***, ***eutrophic*** and ***hypereutrophic***. Lake conditions characteristic of these trophic states are:

Oligotrophic - lack of plant nutrients keep productivity low (i.e. few rooted plants, no algae blooms); lake contains oxygen at all depths; clear water; deeper lakes can support trout.

Mesotrophic - moderate plant productivity; hypolimnion may lack oxygen in summer; moderately clear water; warm water fisheries only - bass and perch may dominate.

Eutrophic - contains excess nutrients; blue-green algae dominate during summer; algae scums are probable at times; hypolimnion lacks oxygen in summer; poor transparency; rooted macrophyte problems may be evident.

Hypereutrophic - algal scums dominate in summer; few macrophytes; no oxygen in hypolimnion; fish kills possible in summer and under winter ice.

The units in the table are either milligrams per liter (mg/L) or micrograms per liter (μg/L). These are only guidelines; similar concentrations in a particular lake may not cause problems if something else is limiting the growth of algae or rooted plants.

Table 44. Mean values of some water quality parameters and their relationship to lake production (after Vollenweider, 1975).

Parameter	Oligotrophic	Mesotrophic	Eutrophic	Hypereutrophic
Total Phosphorus (mg/L)	0.008	0.027	0.084	>0.750
Total Nitrogen (mg/L)	0.661	0.753	1.875	-
Chlorophyll *a* (μg/L)	1.7	4.7	14.3	-

Table 45 shows the mean concentrations of total phosphorus, total nitrogen, and chlorophyll *a* for the Pleasant and Riddles Lakes watershed lakes. All of the lakes' mean total phosphorus concentrations exceed Vollenweider's mean total phosphorus concentrations in eutrophic lakes. Both Fites Lake and Riddles possess mean total nitrogen concentrations in excess of Vollenweider's mean total nitrogen concentration in eutrophic lakes. However, Pleasant Lake's mean total nitrogen concentration is in excess of Vollenweider's mean total nitrogen concentration in mesotrophic lakes. Likewise, Pleasant and Riddles lakes' chlorophyll *a* concentrations were above the mean chlorophyll *a* concentration in Vollenweider's eutrophic lakes, while Fites Lake's chlorophyll *a* concentration exceeded the mean chlorophyll *a* concentration in Vollenweider's mesotrophic lakes. This comparison indicates that both Pleasant and Riddles lakes are very productive in nature and that the plankton community realizes a majority of its potential productivity. Fites Lake possesses adequate nutrient concentrations to be very productive; however, its chlorophyll *a* concentration indicates that the lake is only moderately productive. Something other than nutrient concentrations is likely limiting the plankton productivity in Fites Lake.

Table 45. Comparison of mean total phosphorus, total nitrogen, and chlorophyll *a* results for the Pleasant and Riddles Lakes watershed lakes with Vollenweider's trophic classes.

Lake	Mean TP (mg/L)	Trophic Class	Mean TN (mg/L)	Trophic Class	Chlophyll *a* (μg/L)	Trophic Class
Pleasant	0.404	eutrophic	1.787	mesotrophic	37.1	eutrophic
Fites	0.079	eutrophic	2.367	eutrophic	8.3	mesotrophic
Riddles	0.554	eutrophic	1.937	eutrophic	44.0	eutrophic

Comparison with Other Indiana Lakes

Pleasant, Fites, and Riddles lakes results can also be compared with other Indiana lakes. Table 46 presents data from 456 Indiana lakes collected during July and August from 1994 to 2004 under the Indiana Clean Lakes Program. The set of data summarized in the table are mean values obtained by averaging the epilimnetic and hypolimnetic pollutant concentrations in samples from each of the 456 lakes. It should be noted that a wide variety of conditions, including geography, morphometry, time of year, and watershed characteristics, can influence the water quality of lakes. Thus, it is difficult to predict and even explain the reasons for the water quality of a given lake.

Table 46. Water quality characteristics of 456 Indiana lakes sampled from 1994 through 2004 by the Indiana Clean Lakes Program. Means of epilimnion and hypolimnion samples were used.

	Secchi Disk (ft)	NO_3 (mg/L)	NH_4 (mg/L)	TKN (mg/L)	SRP (mg/L)	TP (mg/L)	Chl *a* (µg/L)	Plankton (#/L)	Blue-Green Dominance
Minimum	0.3	0.01	0.004	0.230	0.01	0.01	0.013	39	0.08%
Maximum	32.8	9.4	22.5	27.05	2.84	2.81	380.4	753,170	100%
Median	6.9	0.275	0.818	1.66	0.12	0.17	12.9	35,570	53.8%

Table 47 compares the mean of selected water quality parameters for Pleasant, Fites, and Riddles lakes to median value for all Indiana lakes. (Appendix G details comparison of these lakes' water quality with the median concentration for Indiana lakes.) All three of the lakes exhibited poorer transparency than most Indiana lakes. Riddles Lake contained a lower density plankton population than those present in most Indiana Lakes; however, the lake's chlorophyll *a* concentration was higher than chlorophyll *a* concentrations present in most Indiana lakes. However, Pleasant Lake's plankton density and chlorophyll *a* concentrations were both poorer than similar parameters measured in most Indiana lakes. Both Pleasant and Riddles lakes possessed higher soluble reactive and total phosphorus concentrations than most Indiana lakes. Fites Lake faired the best in its comparison. Fites Lake was better than the median of all sampled lakes in all parameters except total Kjeldahl nitrogen concentration, blue-green algal dominance, and Secchi disk transparency. Pleasant and Riddles lakes faired the worst in this comparison. Seven of Pleasant and Riddles lakes water quality parameters were worse than the median values for those parameters in Indiana lakes. For Pleasant Lake, Secchi disk transparency, total Kjeldahl nitrogen concentration, soluble reactive phosphorus concentration, total phosphorus concentration, chlorophyll *a* concentration, plankton density, and blue-green algal dominance were all worse than most Indiana lakes. For Riddles Lake, many of these same parameters, including Secchi disk transparency, ammonia concentration, total Kjeldahl nitrogen concentration, soluble reactive phosphorus concentration, total phosphorus concentration, chlorophyll *a* concentration, and blue-green algal dominance were worse than the median values for those parameters in Indiana lakes.

Table 47. Comparison of Pleasant, Fites, and Riddles lakes data to the median for all Indiana lakes for selected water parameters.

Lake	Secchi Disk	NO_3	NH_4	TKN	SRP	TP	Chl *a*	Plankton	Blue-Green Dominance
Pleasant	worse	better	better	worse	worse	worse	worse	worse	worse
Fites	worse	better	better	worse	better	better	better	better	worse
Riddles	worse	better	worse	worse	worse	worse	worse	better	worse

Using a Trophic State Index

In addition to simple comparisons with other lakes, lake water quality data can be evaluated through the use of a trophic state index or TSI. Indiana and many other states use a trophic state index (TSI) to help evaluate water quality data. A TSI condenses water quality data into a single, numeric index.

Different index (or eutrophy) points are assigned for various water quality concentrations. The index total, or TSI, is the sum of individual eutrophy points for a lake.

The Indiana TSI

The Indiana TSI (ITSI) was developed by the Indiana Stream Pollution Control Board and published in 1986 (IDEM, 1986). The original ITSI differed slightly from the one in use today. Today's ITSI uses ten different water quality parameters to calculate a score. Table 48 shows the point values assigned to each parameter.

Table 48. The Indiana Trophic State Index.

Parameter and Range		Eutrophy Points
I.	Total Phosphorus (ppm)	
	A. At least 0.03	1
	B. 0.04 to 0.05	2
	C. 0.06 to 0.19	3
	D. 0.2 to 0.99	4
	E. 1.0 or more	5
II.	Soluble Phosphorus (ppm)	
	A. At least 0.03	1
	B. 0.04 to 0.05	2
	C. 0.06 to 0.19	3
	D. 0.2 to 0.99	4
	E. 1.0 or more	5
III.	Organic Nitrogen (ppm)	
	A. At least 0.5	1
	B. 0.6 to 0.8	2
	C. 0.9 to 1.9	3
	D. 2.0 or more	4
IV.	Nitrate (ppm)	
	A. At least 0.3	1
	B. 0.4 to 0.8	2
	C. 0.9 to 1.9	3
	D. 2.0 or more	4
V.	Ammonia (ppm)	
	A. At least 0.3	1
	B. 0.4 to 0.5	2
	C. 0.6 to 0.9	3
	D. 1.0 or more	4

VI. Dissolved Oxygen: Percent Saturation at 5 feet from surface

A.	114% or less	0
B.	115% to 119%	1
C.	120% to 129%	2
D.	130% to 149%	3
E.	150% or more	4

VII. Dissolved Oxygen: Percent of measured water column with at least 0.1 ppm dissolved oxygen

A.	28% or less	4
B.	29% to 49%	3
C.	50% to 65%	2
D.	66% to 75%	1
E.	76% to 100%	0

VIII. Light Penetration (Secchi Disk)

A.	Five feet or under	6

IX. Light Transmission (Photocell) : Percent of light transmission at a depth of 3 feet

A.	0 to 30%	4
B.	31% to 50%	3
C.	51% to 70%	2
D.	71% and up	0

X. Total Plankton per liter of water sampled from a single vertical tow between the 1% light level and the surface:

A.	less than 3,000 organisms/L	0
B.	3,000 - 6,000 organisms/L	1
C.	6,001 - 16,000 organisms/L	2
D.	16,001 - 26,000 organisms/L	3
E.	26,001 - 36,000 organisms/L	4
F.	36,001 - 60,000 organisms/L	5
G.	60,001 - 95,000 organisms/L	10
H.	95,001 - 150,000 organisms/L	15
I.	150,001 - 5000,000 organisms/L	20
J.	greater than 500,000 organisms/L	25
K.	Blue-Green Dominance: additional points	10

Values for each water quality parameter are totaled to obtain an ITSI score. Based on this score, lakes are then placed into one of five categories:

TSI Total	Water Quality Classification
0-15	Oligotrophic
16-31	Mesotrophic
32-46	Eutrophic
47-75	Hypereutrophic

These categories correspond to the qualitative lake productivity categories described earlier. An increasing TSI score for a particular lake from one year to the next indicates that water quality is worsening, while a lower TSI score indicates improved conditions. However, natural factors such as climate variation can cause changes in TSI scores that do not necessarily indicate a long-term change in lake condition. (Jones (1996) suggests that changes in TSI scores of 10 or more points are indicative of changes in trophic status, while smaller changes in TSI scores may be more attributable to natural fluctuations in water quality parameters.)

At the time of the July 18, 2005 sampling, Pleasant Lake possessed the highest ITSI score (42), followed by Riddles Lake with a score of 41, while Fites Lake possessed an ITSI value of 32. These values place all three lakes in the eutrophic category. However, Fites Lake's ITSI score is approximately 10 points lower than the scores calculated for Pleasant and Riddles lakes. This suggests that although all three lake are very productive, Fites Lake may possess marginally better water quality. These conclusions are generally consistent with results obtained from the comparison of the lakes' data to Vollenweider's data (Table 45), which suggested that the lakes were mesotrophic to eutrophic in nature. As will be described later in this section, the ITSI scores for these lakes generally approximate better water quality conditions for these lakes than those determined using Carlson's TSI.

Because the ITSI captures one snapshot of a lake in time, using the Indiana TSI to track trends in lake productivity may be the best use of the Indiana TSI. Table 49 presents historical Indiana TSI scores for Pleasant, Fites, and Riddles lakes. No clear trend is observable from for Pleasant and Riddles lakes' ITSI scores. (This is the first assessment completed on Fites Lake; therefore, no trend information is available at this time.) The ITSI scores for Pleasant and Riddles lakes in the 1970s are similar to the 1999 and 2004 ITSI scores. However, the ITSI scores from the current study are more similar to the 1995 ITSI scores. The 1995 ITSI scores are quite a bit higher than scores from any of the other historic assessments. The high ITSI scores from these lakes reflect the heavy reliance on algal parameters in the calculation of the ITSI. For example, in 1995, Pleasant Lake received 20 points due to algae alone resulting in a rather high ITSI score. The same holds true for Riddles Lake in 1995. The scores may be more of a reflection of a one time event (an algal bloom) than the lake's true trophic state. Another explanation of these data suggests that the low ITSI scores for the 1999 sampling result due to drought conditions that occurred throughout that sampling season. Many of the samples collected during the 1999 sampling period possessed relatively low nutrient concentrations with the plankton population being dominated by non-blue-green algae. An extremely high chlorophyll *a* concentration was present in Pleasant Lake during the 2004 assessment. It is suspected that the densest algae concentration was beneath the 3-foot (1-m) sampling depth and therefore, was not collected in the nutrient samples. This resulted in lower than normal ITSI scores.

Table 49. Pleasant, Fites, and Riddles lakes Indiana Trophic State Index scores for sampling conducted between the 1970s and 2004.

Lake	1970s	1990	1995	1999	2004	2005
Pleasant Lake	29	33	49	25	28	42
Fites Lake	--	--	--	--	--	32
Riddles Lake	30	29	48	27	--	41

Using the ITSI to compare Pleasant, Fites, and Riddles lakes to other lakes in the region, Pleasant, Fites, and Riddles lakes' water quality is poorer than most lakes in the region. Based on data collected by the Indiana Clean Lakes Program 1999 assessment, approximately 31% of the lakes in the Kankakee River Basin (which includes the Pleasant and Riddles Lakes watershed) were classified as oligotrophic (IDEM, 2000). Another 59% rated as mesotrophic. Nine percent fell in the eutrophic category, while less than 1% fell in the hypereutrophic category. Pleasant, Fites, and Riddles lakes placement in the eutrophic category based on the ITSI suggests that their water quality is among the poorest 10% of lakes in the region when ranked by water quality. This evaluation is consistent with the comparison of raw data scores for Pleasant and Riddles lakes to those for all lakes in Indiana; however, Fites Lake's water quality data comparison indicates that it Fites lake generally possesses lower nutrient concentrations and plankton densities than most Indiana lakes (Table 49). Based on an overall lake comparison Fites Lake appears to be poorer than 90% of lakes in the Kankakee River Basin.

The Carlson TSI

Developed by Bob Carlson (1977), the Carlson TSI is the most widely used and accepted TSI. Carlson analyzed summertime total phosphorus, chlorophyll *a*, and Secchi disk transparency data for numerous lakes and found statistically significant relationships among the three parameters. He developed mathematical equations for these relationships, and these relationships form the basis for the Carlson TSI. Using this index, a TSI value can be generated by one of three measurements: Secchi disk transparency, chlorophyll *a*, or total phosphorus. Data for one parameter can also be used to predict a value for another. The TSI values range from 0 to 100. Each major TSI division (10, 20, 30, etc.) represents a doubling in algal biomass (Figure 53).

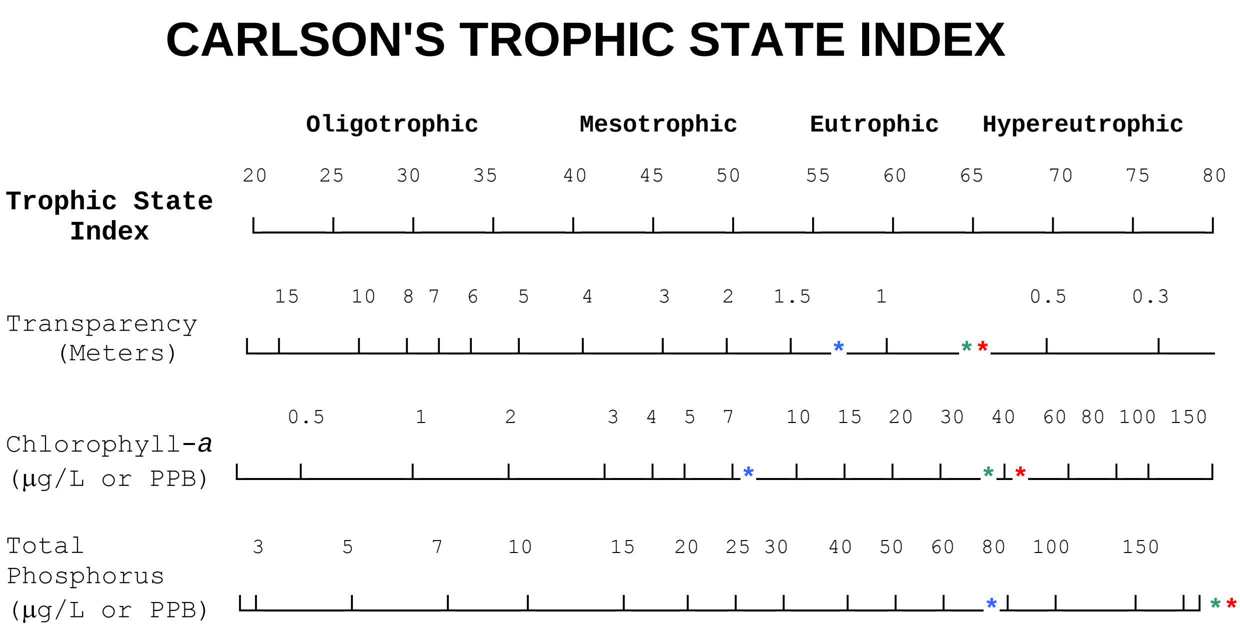

Figure 53. Carlson's Trophic State Index with Pleasant (*), Fites (*), and Riddles (*) lakes results indicated by asterisks.

As a further aid in interpreting TSI results, Carlson's scale is divided into four lake productivity categories: oligotrophic (least productive), mesotrophic (moderately productive), eutrophic (very productive), and hypereutrophic (extremely productive).

Using Carlson's index, a lake with a summertime Secchi disk depth of 1 meter (3.3 feet) would have a TSI of 60 points (located in line with the 1 meter or 3.3 feet). This lake would be in the eutrophic category. Because the index was constructed using relationships among transparency, chlorophyll *a*, and total phosphorus, a lake having a Secchi disk depth of 1 meter (3.3 feet) would also be expected to have 20 μg/L chlorophyll *a* and 48 μg/L total phosphorus.

Not all lakes have the same relationship between transparency, chlorophyll *a*, and total phosphorus as Carlson's lakes do. Other factors such as high suspended sediments or heavy predation of algae by zooplankton may keep chlorophyll *a* concentrations lower than might be otherwise expected from the total phosphorus concentrations or transparency measurements. High suspended sediments would also make transparency worse than otherwise predicted by Carlson's index.

It is also useful to compare the actual trophic state points for a particular lake from one year to the next to detect any trends in changing water quality. While climate and other natural events will cause some variation in water quality over time (possibly 5-10 trophic points), larger point changes may indicate important changes in lake quality.

Analysis of Pleasant, Fites, and Riddles lakes' total phosphorus, transparencies and chlorophyll *a* data using Carlson's TSI suggests that the lakes are moderately to highly productive. In Pleasant and Riddles lakes, their transparency and chlorophyll *a* concentrations suggest that the lakes are eutrophic to hypereutrophic, while their total phosphorus concentrations indicate that the lakes are hypereutrophic in nature (Figure 53; Table 50). Fites Lake's chlorophyll *a* concentration places the lake in the mesotrophic category, while its transparency places it in the eutrophic category, and its total phosphorus concentration indicates that it is more hypereutrophic in nature. The study lakes' high total phosphorus concentrations create conditions suitable for high levels of productivity. However, the moderately poor transparency and moderate chlorophyll *a* concentrations present in Fites Lake indicates that the lake is not reaching its full productive potential. It is likely that something other than light penetration and phosphorus concentration is limiting algal production in this lake. Conversely, Pleasant and Riddles lakes transparency and chlorophyll *a* concentration indicates that the lakes' production more adequately reflects their phosphorus concentration than Fites Lake.

Table 50. Comparison of Pleasant, Fites, and Riddles lakes' trophic state scores and classifications using Carlson's Trophic State Index.

Lake	Phosphorus		Secchi Disk		Chlorophyll *a*	
	TSI	Classification	TSI	Classification	TSI	Classification
Pleasant	90	hypereutrophic	65	eutrophic-hypereutrophic	66	eutrophic-hypereutrophic
Fites	67	hypereutrophic	57	eutrophic	51	mesotrophic-eutrophic
Riddles	95	hypereutrophic	65	eutrophic-hypereutrophic	68	eutrophic-hypereutrophic

As described above, the expected relationship between transparency, chlorophyll *a* concentration, and total phosphorus concentration is that Carlson's TSI score for each is the same. For Pleasant Lake, Carlson's TSI scores using transparency and chlorophyll *a* concentration are roughly equal (TSI (SD) = 65 and TSI (chl *a*) = 66). However, Carlson's TSI score for total phosphorus concentration is much higher (TSI (TP) = 90). When TSI (SD) = TSI (chl *a*) < TSI (TP), something other than phosphorus is limiting algae growth. Potential limiting factors zooplankton grazing and/or nitrogen. The same relationship occurs in Riddles Lake as well. In the case of both Pleasant and Riddles lakes, zooplankton grazing may affect the lake's algal community. (Further studies would be needed to confirm this.) Additionally, the lakes' rooted plant communities may play a role in limiting algae growth. Rooted plants have been shown to secrete alleopathic chemicals preventing algae growth. Again, more research (i.e. year round evaluation of the lake's temperature profile) is needed to determine if this is a factor in limiting algae production.

4.6 Macrophyte Inventory

4.6.1 Macrophyte Inventory Introduction

There are many reasons to conduct an aquatic rooted plant survey as part of a complete assessment of a lake and its watershed. Like other biota in a lake ecosystem (e.g. fish, microscopic plants and animals, etc.), the composition and structure of the lake's rooted plant community often provide insight into the long term water quality of a lake. While sampling the lake water's chemistry (dissolved oxygen, nutrient concentrations, etc.) is important, water chemistry sampling offers a single snapshot of the lake's condition. Because rooted plants live for many years in a lake, the composition and structure of this community reflects the water quality of the lake over a longer term. For example, if one samples the water chemistry of a typically clear lake immediately following a major storm event, the results may suggest that the lake suffers from poor clarity. However, if one examines the same lake and finds that rooted plant species such as northern watermilfoil, white stem pondweed, and large leaf pondweed, all of which prefer clear water, dominate the plant community, one is more likely to conclude that the lake is typically clear and its current state of turbidity is due to the storm rather than being its inherent nature.

The composition and structure of a lake's rooted plant community also help determine the lake's fish community composition and structure. Submerged aquatic vegetation provides cover from predators and is a source of forage for many different species of fish (Valley et al, 2004). However, extensive and dense stands of exotic aquatic vegetation can have a negative impact on the fish community. For example, a lake's bluegill population can become stunted because dense vegetation reduces their foraging ability, resulting in slower growth. Additionally, dense stands reduce predation by largemouth bass and other piscivorous fish on bluegill which results in increased intraspecific competition among both prey and predator species (Olsen et al, 1998). Vegetation removal can have variable results on improving fish growth rates (Cross et al, 1992, Olsen et al, 1998). Conversely, lakes with depauperate plant communities may have difficulty supporting some top predators that require emergent vegetation for spawning. In these and other ways, the lake's rooted plant community illuminates possible reasons for a lake's fish community composition and structure.

A lake's rooted plant community impacts the recreational uses of the lake. Swimmers and power boaters desire lakes that are relatively plant-free, at least in certain portions of the lake. In contrast, anglers prefer lakes with adequate rooted plant coverage, since those lakes offer the best fishing opportunity. Before lake users can develop a realistic management plan for a lake, they must understand the existing rooted plant community and how to manage that community. This understanding is necessary to achieve the recreational goals lake users may have for a given lake.

For the reasons outlined above, as well as several others, JFNew conducted a general macrophyte (rooted plant) survey on Pleasant and Riddles Lakes as part of the overall lake and watershed diagnostic study. Before detailing the results of the macrophyte survey, it may be useful to outline the conditions under which lakes may support macrophyte growth. Additionally, an understanding of the roles that macrophytes play in a healthy, functioning lake ecosystem is necessary for lake users to manage the lake's macrophyte community. The following paragraphs provide some of this information.

Conditions for Growth

Like terrestrial vegetation, aquatic vegetation has several habitat requirements that need to be satisfied in order for the plants to grow or thrive. Aquatic plants depend on sunlight as an energy source. The amount of sunlight available to plants decreases with depth of water as algae, sediment, and other suspended particles block light penetration. Consequently, most aquatic plants are limited to maximum water depths of approximately 10-15 feet (3-4.5 m), but some species, such as Eurasian watermilfoil, have a greater tolerance for lower light levels and can grow in water deeper than 32 feet (10 m) (Aiken et al., 1979). Hydrostatic pressure rather than light often limits plant growth at deeper water depth (15-20 feet or 4.5-6 m).

Water clarity affects the ability of sunlight to reach plants, even those rooted in shallow water. Lakes with clearer water have an increased potential for plant growth. Both Pleasant and Riddles Lakes possess poorer water clarity than the average Indiana lake. The Secchi disk depth measured during the plant survey was 1.7 feet (0.5 m) in both lakes. (This measurement was slightly worse than the Secchi disk depth measured for the lakes during the in-lake sampling portion of the study. Secchi disk depth measured 2.3 feet (0.7 m) in both Pleasant and Riddles Lakes during the in-lake sampling portion.) As a general rule of thumb, rooted plant growth is restricted to the portion of the lake where water depth is less than or equal to 2-3 times the lake's Secchi disk depth. This is generally true in Pleasant and Riddles Lakes, where rooted plants were observed in water to a depth of approximately 5 feet (1.5 m), which is approximately 3 times the lakes' average Secchi disk depth.

Aquatic plants also require a steady source of nutrients for survival. Many aquatic macrophytes differ from microscopic algae (which are also plants) in their uptake of nutrients. Aquatic macrophytes receive most of their nutrients from the sediments via their root systems rather than directly utilizing nutrients in the surrounding water column. Some competition with algae for nutrients in the water column does occur. The amount of nutrients taken from the water column varies for each macrophyte species. Because macrophytes obtain most of their nutrients from the sediments, lakes which receive high watershed inputs of nutrients to the water column will not necessarily have aquatic macrophyte problems.

A lake's substrate and the forces acting on the substrate also affect a lake's ability to support aquatic vegetation. Lakes that have mucky, organic, nutrient-rich substrates have an increased potential for plant growth compared to lakes with gravelly, rocky substrates. Sandy substrates that contain sufficient organic material typically support healthy aquatic plant communities. Lakes that have significant wave action that disturb the bottom sediments have decreased ability to support plants. Disturbance of bottom sediment may decrease water clarity, limiting light penetration, or may affect the availability of nutrients for the macrophytes. Wave action may also create significant shearing forces prohibiting plant growth altogether.

Boating activity may affect macrophyte growth in conflicting ways. Rooted plant growth may be limited if boating activity regularly disturbs bottom sediments. Alternatively, boating activity in rooted plant stands of species that can reproduce vegetatively, such as Eurasian watermilfoil, may increase macrophyte density rather than decrease it. Boating activity may be increasing the size and density of the Eurasian watermilfoil stands in both Pleasant and Riddles Lakes.

Ecosystem Roles

Aquatic plants are a beneficial and necessary part of healthy lakes. Plants stabilize shorelines holding bank soil with their roots. The vegetation also serves to dissipate wave energy further protecting shorelines from erosion. Plants play a role in a lake's nutrient cycle by up-taking nutrients from the sediments. Like their terrestrial counterparts, aquatic macrophytes produce oxygen which is utilized by the lake's fauna. Plants also produce flowers and unique leaf patterns that are aesthetically attractive.

Emergent and submerged plants provide important habitat for fish, insects, reptiles, amphibians, waterfowl, shorebirds, and small mammals. Fish utilize aquatic vegetation for cover from predators and for spawning and rearing grounds. Different species depend upon different percent coverages of these plants for successful spawning, rearing, and protection for predators. For example, bluegill require an area to be approximately 15-30% covered with aquatic plants for successful survival, while northern pike achieve success in areas where rooted plants cover 80% or more of the area (Borman et al., 1997).

Aquatic vegetation also serves as substrate for aquatic insects, the primary diet of insectivorous fish. Waterfowl and shorebirds depend on aquatic vegetation for nesting and brooding areas. Numerous aquatic waterfowl were observed utilizing Pleasant and Riddles Lakes as habitat during the macrophyte survey. Aquatic plants such as pondweed, coontail, duckweed, watermilfoil, and arrowhead, also provide a food source to waterfowl. Duckweed in particular has been noted for its high protein content and consequently has served as feed for livestock. Turtles and snakes utilize emergent vegetation as basking sites. Amphibians rely on the emergent vegetation zones as primary habitat.

4.6.2 Macrophyte Inventory Methods

JFNew surveyed Pleasant and Riddles Lakes on July 27, 2005 according to the Indiana State Tier One sampling protocol (IDNR, 2004). JFNew examined the entire littoral zone of the lakes. As defined in the protocol, the lakes' littoral zone was estimated to be approximately three times the lake's Secchi disk depth. This estimate approximates the 1% light level, or the level at which light penetration into the water column is sufficient to support plant growth. (See the **Lake Assessment** section for a full discussion of the 1% light level and the reading recorded during the in-lake sampling effort.) At the time of sampling, both Pleasant and Riddles lakes' Secchi disk depth was 1.7 feet (0.5 m); thus, their 1% light level was estimated to be approximately 5.1 feet (1.5 m). Consequently, JFNew sampled the area of Pleasant and Riddles lakes that were less than approximately 5 feet (1.5 m) deep.

A survey crew consisting of one aquatic ecologist, one botanist, and a citizen volunteer boat driver surveyed Pleasant and Riddles lakes in a clockwise manner. The Riddles Lake tour began at the lake's northwest corner at the Conservation Club channel while the Pleasant Lake tour started at the lake's boat ramp at the north end of the lake. The survey crew drove their boat in a zig-zag pattern across the littoral zone of the lakes while visually identifying plant species. The crew maintained a tight pattern to ensure that the entire zone was observed. While the estimated littoral zones of the lakes were quite shallow allowing for good visual identification of plant species, in areas of dense plant coverage, rake grabs were performed to ensure all species were identified. Once the crew had visually surveyed an entire plant bed, the crew broadly estimated species abundance, canopy coverage by strata (emergent, rooted floating, non-rooted floating, and submerged), and bed size.

The crew also noted the bed's bottom substrate type. The crew recorded all data on data sheets (Appendix H). After completing one bed, the crew continued surveying the littoral zone until all plant beds were identified and the appropriate data were recorded.

4.6.3 Macrophyte Inventory Results

Riddles Lake

Riddles Lake supports an extensive rooted plant community. The community extends from the lake's shoreline to water that is just over 5 feet (1.5 m) deep. This is consistent with the estimated extent of the littoral zone based on the lake's Secchi disk depth of 1.7 feet (0.5 m), measured at the time of the aquatic plant survey. (Three times the Secchi disk depth is 5.1 feet (0.5 m).) Riddles Lake's aquatic plant community can be roughly divided into four beds that differ in community composition and structure (Table 51). Figure 54 shows the approximate location and extent of each bed.

Table 51. Riddles Lake plant community species canopy cover by plant bed.

Common Name	Scientific Name	Bed 1	Bed 2	Bed 3	Bed 4
Arrow arum	*Peltandra virginica*	<2%	<2%	<2%	<2%
Barnyard grass	*Echinochloa crusgalli*				<2%
Bladderwort species	*Utricularia species*		<2%		
Broad leaved cattail	*Typha latifolia*		2-20%	<2%	2-20%
Bulblet-bearing water hemlock	*Cicuta bulbifera*				<2%
Buttonbush	*Cephalanthus occidentalis*		<2%		
Chairmakers rush	*Scirpus pungens*				<2%
Clearweed	*Pilea pumila*			<2%	
Common arrowhead	*Sagittaria latifolia*				<2%
Common burreed	*Sparganeum eurycarpum*				<2%
Common duckweed	*Lemna minor*	2-20%	2-20%	<2%	<2%
Common water horehound	*Lycopus americanus*			<2%	
Common water plantain	*Alisma subcordatum*				<2%
Coontail	*Ceratophyllum demersum*	<2%	21-60%	2-20%	21-60%
Curly leaf pondweed	*Potamogeton crispus*		<2%		
Dock species	*Rumex species*		<2%		
Eurasian watermilfoil	*Myriophyllum spicatum*		<2%	<2%	2-20%
False nettle	*Boehmeria cylindrica*		<2%		<2%
Filamentous algae	*Filamentous algae*		2-20%	2-20%	2-20%
Hybrid cattail	*Typha glauca*		2-20%	<2%	
Lady's thumbprint	*Polygonum persicaria*		<2%		
Large duckweed	*Spirodela polyrhiza*	<2%	<2%	<2%	<2%
Leafy pondweed	*Potamogeton foliosis*		2-20%		
Narrow leaved cattail	*Typha angustifolia*		<2%	2-20%	
Needle spike rush	*Eleocharis acicularis*				<2%

Common Name	Scientific Name	Bed 1	Bed 2	Bed 3	Bed 4
Nodding bur marigold	*Bidens cernua*		<2%		<2%
Nodding smartweed	*Polygonum lapathifolia*		<2%	<2%	<2%
Pickerel weed	*Pontedaria cordata*		<2%	2-20%	<2%
Purple loosestrife	*Lythrum salicaria*		2-20%	<2%	<2%
Reed canary grass	*Phalarus arundinacaea*		<2%		<2%
Rice cut grass	*Leersia oryzoides*		<2%		<2%
Slender water weed	*Elodea nuttallii*		<2%		
Softstem bulrush	*Scirpus validus*		<2%	<2%	
Southern naiad	*Najas guadalupensis*		<2%	2-20%	2-20%
Spatterdock	*Nuphar advena*	2-20%	21-60%		21-60%
Spotted touch-me-not	*Impatiens capensis*		<2%	<2%	
Star duckweed	*Lemna trisulca*		<2%		<2%
Water heartsease	*Polygonum coccineum*		<2%		
Water meal	*Wolffia columbiana*	>60%	21-60%	2-20%	2-20%
Whirled loosestrife	*Decodon verticillatus*		<2%	<2%	<2%
White water lily	*Nyphaea tuberosa*	2-20%	2-20%	<2%	2-20%

In total, approximately 40 aquatic plant species inhabit the water and shoreline of Riddles Lake. The LARE protocol used to conduct the aquatic plant survey requires surveyors to note all plant species observed from a boat. Thus, plants in the wetland complexes adjacent to the lake were only counted if they were visible from the boat. If these wetland complexes had been explored in greater detail, it is likely that the total number of plant species would increase significantly.

The aquatic plant survey of Riddles Lake revealed the presence of 40 species throughout the lake. The northern and southern ends of the lake possessed the greatest diversity and density of plants. Riddles Lake has representative species from all three strata (emergent, floating, and submerged) of plant communities. Emergent plant species are the most diverse group in the lake accounting for 65% (25 species) of the total plant species by number. Most of these emergent species were present in low numbers. The exceptions to this are purple loosestrife, pickerel weed, and cattails. Only seven submerged species grow in Riddles Lake. Of these, two are not native to Indiana lakes including Eurasian watermilfoil and curly leaf pondweed. One other, coontail, established thick, potentially nuisance stands in some areas. Floating plant species were also predominant within the Riddles Lake plant community. Spatterdock, white water lily, water meal, duckweed, and filamentous algae dominated the floating strata of Riddles Lake.

Riddles Lake's plant community covers approximately 37% (28 acres or 11.6 ha) of the lake's surface area. Canopy coverage is generally fairly dense around most of the lake, with submerged species accounting for most of the coverage in each plant bed except the bed located within the Conservation Club channel (Bed 01). Canopy coverage of the submerged portion of the community ranges from 21 to 60% canopy cover in Riddles Lake. In contrast, canopy coverage of emergent strata is sparse. Emergent species accounted for only 2 to 20% of the canopy coverage in all four plant beds. Canopy coverage of the floating strata varies across the lake. In two of the three main lake beds, the floating species covered more than 20% of the bed. In Bed 03, however, canopy coverage of the floating species was less than 2%. This is to be expected as Bed 03 is located adjacent to residential shoreline, where most of the floating and emergent species were removed to provide access to the lake.

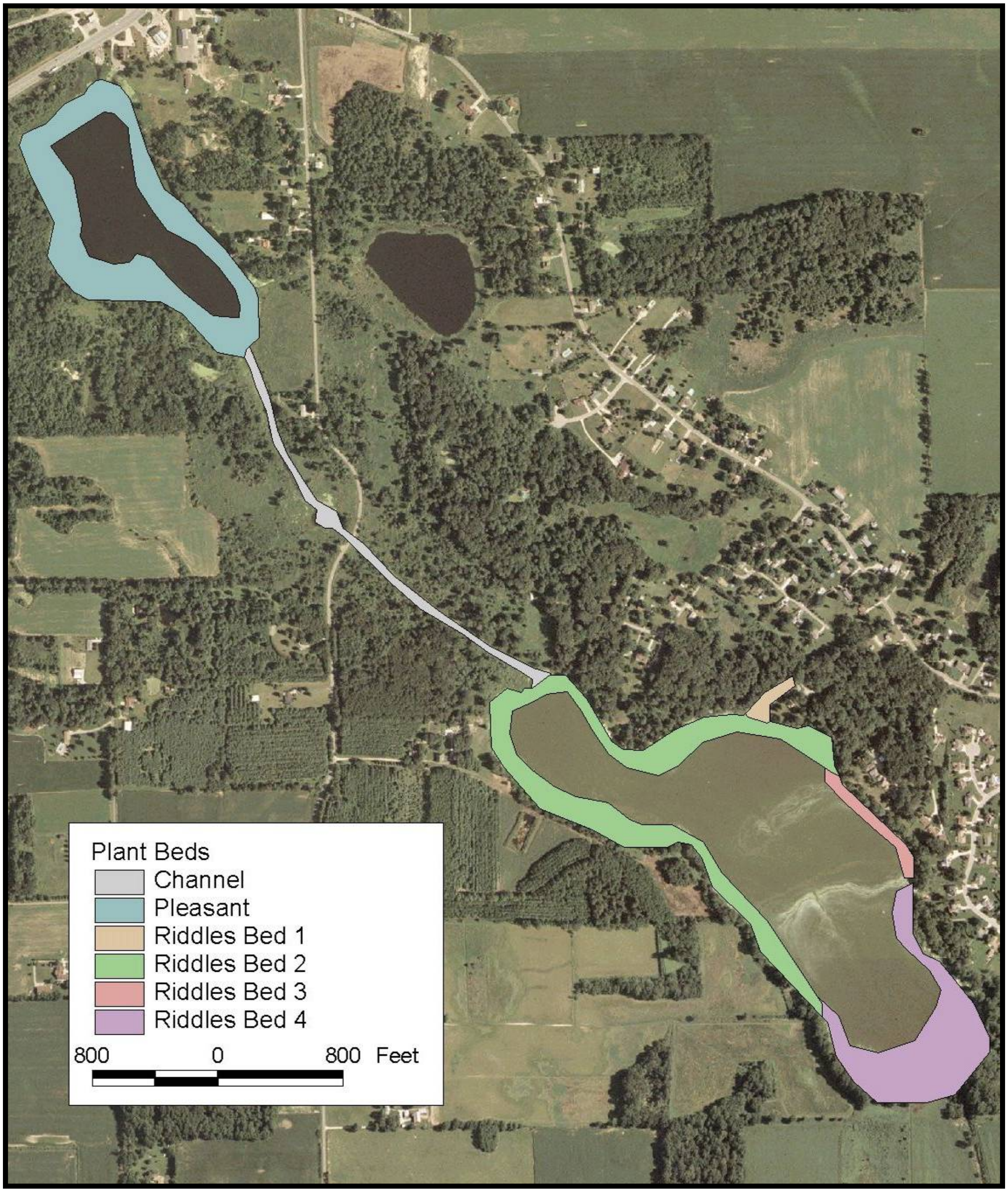

Figure 54. Pleasant and Riddles lakes plant beds as surveyed July 27, 2005. Scale: 1"=600'.

The following paragraphs detail each of the four plant beds in Riddles Lake (Figure 54). Appendix H contains a list of species found in each bed during the plant survey. Both common and scientific name are provided in the list. Appendix H also includes the data sheets prepared for Riddles Lake.

Bed 01

Bed 01 is the least diverse plant bed on the lake. It also covers the smallest area (0.7 acre or 0.3 ha). Located in the Conservation Club channel, Bed 01 is relatively isolated from the rest of Riddles Lake and supports only 7 species. The non-rooted floating plant watermeal dominated the plant community within Bed 01 accounting for more than 60% of the bed's canopy cover. White water lily, spatterdock, and minor duckweed were also prevalent within Bed 01 covering 2 to 20% of the bed's canopy. Coontail, the only submerged species observed within the plant bed, was limited in its growth covering less than 2% of the bed's canopy cover. The lack of stable shoreline and visible shoreline erosion that is occurring within the channel limits the ability for emergent plant species to grow in this area (Figure 55).

Figure 55. Shoreline erosion within the Conservation Club channel at Riddles Lake.

Bed 02

Bed 02 covers the northeastern, northern, and northwestern shorelines of Riddles Lake including most of the area that possesses a natural shoreline and remains undeveloped. This is the largest plant bed mapped for Riddles Lake covering 15.4 acres (6.2 ha) or 20% of Riddles Lake's surface area. The presence and predominance of floating species marks the transition between Beds 02 and 03 (Figure 56). Watermeal, spatterdock, and coontail are co-dominant within Bed 02. Each of these species accounts for 21 to 60% of Bed 02's canopy cover. White water lily, minor duckweed, and filamentous algae are predominant within the bed's floating strata accounting for 2 to 20% of the bed's canopy cover. Purple loosestrife and cattails dominate the emergent plant community accounting for 2 to 20% of the bed's canopy cover. The exotic species, reed canary grass, was also present in low numbers along the shoreline adjacent to Bed 02. Submerged species account for only 7 of the 32 species identified in Bed 02; however, they cover 21 to 60% of Bed 02's surface area. Coontail and leafy pondweed dominate the submerged community; curly-leaf pondweed, bladderwort, southern naiad, and Eurasian watermilfoil are also common submerged species in Bed

02. Bed 02 also supports four exotic species: purple loosestrife, reed canary grass, Eurasian watermilfoil, and curly-leaf pondweed. Purple loosestrife accounts for 2 to 20% of the bed's canopy over, while the remaining three species individually accounted for less than 2% of the Bed 02's canopy cover.

Figure 56. Floating strata of Bed 02. Note the thick watermeal cover mixed with spatterdock and white water lilies within this plant bed.

Bed 03

Bed 03 occupies the shallow water in front of Riddles Lake's developed, eastern shoreline. It covers only 1.4 acres (0.6 ha) of Riddles Lake. Bed 03's limited floating strata separates Bed 03 from Beds 02 and 04. Bed 03 supports 20 species. A majority of these species (12 of 20) are in the emergent strata; however, these are generally present in low densities which account for only 2 to 20% of the canopy cover. Rooted floating and non-rooted floating species account for only 4 of the 20 species present in Bed 03 and cover less than 2% and 2 to 20% of the canopy cover of Bed 03, respectively. Submerged species cover the largest percentage of the bed's canopy (21 to 60%); however, they are present in low diversity. Coontail, filamentous algae, southern naiad, cattails, pickerel weed, and watermeal are co-dominant with each species covering 2 to 20% of the plant bed's canopy cover. Many landowners adjacent to Bed 03 left the shoreline strata of emergent, floating, submerged intact (Figure 57), while others have cleared the shoreline to allow better access to the lake (Figure 58). Two exotic species, Eurasian watermilfoil and purple loosestrife, were present within Bed 03. In total, these species individually accounted for less than 2% of the plant bed's canopy cover.

Figure 57. Natural shoreline adjacent to Bed 03 along Riddles Lake's eastern shoreline. Note the presence of forested and emergent species zones.

Figure 58. Limited submerged, emergent, and forested zones along Bed 03's shoreline.

Bed 04

Bed 04 covers the southern end of Riddles Lake accounting for 11 acres (4.5 ha) or 14% of Riddles Lake's surface area. The predominance of submerged and floating species mark the transition from Bed 03 to 04 (Figure 59). In total, 27 species were identified within Bed 04. Submerged and rooted floating strata dominate the plant community within Bed 04 accounting for 21 to 60% of the bed's canopy cover. Emergent and non-rooted floating species have approximately equal canopy cover; each stratum accounts for less than 20% of Bed 04's canopy cover. However, the submerged and floating plant strata are less diverse than the emergent strata; three submerged, seven floating, and sixteen emergent species were identified in Bed 04. Coontail and spatterdock are co-dominant within the bed each accounting for 21 to 60% of the bed's canopy cover. After coontail, Eurasian watermilfoil and southern naiad possessed the greatest canopy cover for submerged species. White water lily and watermeal each cover 2 to 20% of Bed 04's canopy accounting for the largest portion of the floating plant community after spatterdock. Pickerel weed and cattail created the greatest canopy cover of the emergent species accounting for 2 to 20% of the plant bed's cover. Common water plantain, bur marigold, false nettle, whirled loosestrife, barnyard grass, spike rush, rice cut grass, purple loosestrife, arrow arum, reed canary grass, common arrowhead, chairmakers rush, and common burreed were also present within Bed 04's emergent plant community. Three invasive species, purple loosestrife, common reed, and Eurasian watermilfoil, were observed scattered throughout Bed 04.

Figure 59. Spatterdock and watermeal cover the canopy within Bed 04 along Riddles Lake's southern end. Note the predominant natural shoreline buffer adjacent to the lake.

Pleasant Lake

Like Riddles Lake, Pleasant Lake also supports an extensive rooted plant community. The community extends from the lake's shoreline to water that is over 5 feet (1.5 m) deep. This is consistent with the estimated extent of the littoral zone based on the lake's Secchi disk depth of 1.7 feet (0.5 m), measured at the time of the aquatic plant survey. (Three times the Secchi disk depth is

5.1 feet (0.5 m).) One plant bed rings the entirety of Pleasant Lake's shoreline (Table 52). Figure 51 shows the approximate location and variation of the plant bed within Pleasant Lake. Appendix H contains a list of species found in Pleasant Lake during the plant survey. Both common and scientific name are provided in the list. Appendix H also included the data sheets prepared for Pleasant Lake.

Table 52. Pleasant Lake plant community species canopy cover.

Common Name	Scientific Name	Pleasant Lake
Arrow arum	*Peltandra virginica*	2-20%
Broad leaved cattail	*Typha latifolia*	2-20%
Bulblet-bearing water hemlock	*Cicuta bulbifera*	<2%
Buttonbush	*Cephalanthus occidentalis*	<2%
Common duckweed	*Lemna minor*	2-20%
Coontail	*Ceratophyllum demersum*	21-60%
Curly leaf pondweed	*Potamogeton crispus*	<2%
Eurasian watermilfoil	*Myriophyllum spicatum*	2-20%
False nettle	*Boehmeria cylindrica*	<2%
Filamentous algae	*Filamentous algae*	21-60%
Large duckweed	*Spirodela polyrhiza*	<2%
Leafy pondweed	*Potamogeton foliosis*	<2%
Narrow leaved cattail	*Typha angustifolia*	<2%
Nodding smartweed	*Polygonum lapathifolia*	<2%
Pickerel weed	*Pontedaria cordata*	2-20%
Purple loosestrife	*Lythrum salicaria*	<2%
Reed canary grass	*Phalarus arundinacaea*	<2%
Rice cut grass	*Leersia oryzoides*	<2%
Silver maple	Acer saccharium	<2%
Southern naiad	*Najas guadalupensis*	<2%
Spatterdock	*Nuphar advena*	21-60%
Spotted touch-me-not	*Impatiens capensis*	<2%
Star duckweed	*Lemna trisulca*	<2%
Water meal	*Wolffia columbiana*	21-60%
Whirled loosestrife	*Decodon verticillatus*	<2%
White water lily	*Nyphaea tuberosa*	2-20%

The aquatic plant survey of Pleasant Lake revealed the presence of 26 species throughout the lake. The density of plants was relatively uniform within Pleasant Lake; aquatic plants cover approximately 17.3 acres (7.0 ha) within Pleasant Lake or 75% of Pleasant Lake's surface area. Coontail, Eurasian watermilfoil, filamentous algae, spatterdock, and watermeal are co-dominant within the lake accounting for 21 to 60% of the lake's canopy cover (Figure 60). White water lily, pickerel weed, cattails, arrow arum, duckweed, and Eurasian watermilfoil are also prevalent within the lake.

Figure 60. Spatterdock, white water lilies, and watermeal covering the water's surface in Pleasant Lake.

Like Riddles Lake, Pleasant Lake has representative species from all three strata (emergent, floating, and submerged) of plant communities. Emergent plant species are the most diverse group in the lake accounting for 54% (14 species) of the total plant species by number. Most of these emergent species were relatively dense along much of the shoreline (Figure 60). Cattails, arrow arum, and pickerel weed dominated the emergent strata within Pleasant Lake. False nettle, silver maple, whirled loosestrife, rice cut grass, purple loosestrife, and reed canary grass were also present in and around Pleasant Lake. Only five submerged species grow in Pleasant Lake; however, most of these species are especially dense within the lake. Coontail accounts for 21 to 60% of the canopy cover within the lake, while Eurasian watermilfoil accounts for an additional 2 to 20% of the canopy cover. The other submerged species, narrow leaf pondweed, curly leaf pondweed, and southern naiad, each accounted for less than 2% of the bed's canopy cover. Of the emergent species present in Pleasant Lake, two are not native to Indiana lakes (Eurasian watermilfoil and curly leaf pondweed). Coontail and Eurasian watermilfoil have established thick, potentially nuisance stands in some areas, which is of concern to the health of Pleasant Lake. Floating plant species were also prevalent within the Pleasant Lake plant community. Spatterdock, white water lily, water meal, duckweed, and filamentous algae dominated the floating strata of Pleasant Lake. Four exotic species, purple loosestrife, reed canary grass, curly leaf pondweed, and Eurasian watermilfoil, were observed within Pleasant Lake. Purple loosestrife is especially dense in areas around the lake, such as adjacent to the boat ramp (Figure 61); however, it is limited in its coverage throughout the plant bed. (Beetles targeted for the control of purple loosestrife were released at the public access site in 1996. Rich Dunbar (IDNR Division of Nature Preserves) reports a reduction in purple loosestrife plant height and density at the boat ramp since that time (personal communication).) Eurasian watermilfoil is extremely dense in some areas of the plant bed.

Figure 61. Purple loosestrife adjacent to the Pleasant Lake boat ramp.

Riddles Lake's plant community covers nearly 60% (17.3 acres or 7.0 ha) of the lake's surface area. Canopy coverage is generally fairly dense around most of the lake, with submerged and floating species accounting for most of the coverage in the lake. The submerged, rooted floating, and non-rooted floating portions of the community account for 21 to 60% of the total canopy coverage, while the emergent portion accounted for less than 20% of the canopy. In most areas of the lake, the natural shoreline remains intact and transitions from emergent to floating to submerged plant species. However, there are areas where the vegetation has been removed to gain access to the lake (Figure 62). These are generally limited to narrow areas in front of houses and adjacent to piers. An area of concern is the presence of a horse within Pleasant Lake. The horse has unlimited access to the lake and likely disturbs the plant community within its normal grazing area (Figure 63).

Figure 62. Typical views of the Pleasant Lake plant community where landowners gain access to the lake.

Figure 63. Horse pastured within and adjacent to Pleasant Lake.

Heston Ditch between Pleasant and Riddles Lakes

JFNew assessed the macrophyte community growing in the channel between Pleasant and Riddles Lakes (Figure 64). Appendix H contains a list of species found in the channel during the plant survey. Both common and scientific name are provided in the list. Appendix H also included the data sheets prepared for the channel's plant community. In total, 22 plant species representing the three strata were present within the channel. Overall, emergent species dominated the diversity of the community accounting for 10 of the 22 species observed in the channel; however, emergent species cover less than 20% of the canopy within the channel. Submerged and floating species are co-dominant in regards to both density and diversity with each accounting for six species observed within the channel and covering 21 to 60% of the canopy. Spatterdock, coontail, and watermeal dominate the community; white water lily was also prevalent within the channel. All other species account for less than 2% of the canopy cover.

Figure 64. Plant community present within Heston Ditch, which connects Pleasant and Riddles Lakes.

4.6.4 Macrophyte Inventory Discussion

As noted earlier in this section, the composition and structure of a lake's rooted plant community often reflect the long-term water quality of a lake. Limnologists can use rooted plant data to support or better understand results of a chemical analysis of a lake. Because of their relative longevity (compared to the chemical constituents of a lake), rooted plant data may help in confirming trends observed in historical data. Pleasant and Riddles lakes' rooted plant data is no exception. The survey and analysis of the lakes' rooted plant community presented above confirms many of the conclusions drawn from analysis of the lake's water chemistry

Pleasant and Riddles lakes' poor water clarity likely plays a large role in shaping the composition and structure of the aquatic plant community. The lakes' Secchi disk depth, a measure of water clarity, was 1.7 feet (0.5 m) on the day of the plant survey and 2.2 feet (0.7 m) on the day of the in-lake sampling. The median Secchi disk depth for Indiana lakes is nearly three times as deep (6.9 feet or 2.1 m). The 1% light level measured during the in-lake sampling was only 4.5 feet (1.4 m) in Pleasant Lake and 3.4 feet (1.0 m) in Riddles Lake, further highlighting how poor the lakes' water clarity is. (It is important to remember that the 1% light level represents an extreme limit for rooted plant growth; typically only algae exist at or near the 1% light level.) The lack of light penetrating the lakes' water column prevents the growth of rooted plants in water deeper than 5 feet (1.5 m). Similarly, the plant communities' species composition reflects the low light levels. Eurasian watermilfoil and coontail, which dominate lakes' plant community, are both very tolerant of low light levels.

Pleasant and Riddles lakes' productivity also affects the species composition found in the lakes. The lakes possess relatively high nutrient levels and a very high chlorophyll *a* concentration suggesting the lakes are fairly productive. Both Pleasant and Riddles lakes fall in the eutrophic and hypereutrophic ranges when evaluated using the Indiana Trophic State Index (ITSI) or Carlson's Trophic State Index (TSI), respectively. The lakes' plant community reflects this high productivity. Eurasian watermilfoil and coontail, which dominate the lakes' plant communities, are all very tolerant of eutrophic conditions. Similarly, the dominance of species such as watermeal, duckweed, and filamentous algae in some locations is not surprising since these are species that can utilize nutrients directly from the water column. Given the high nutrient levels in Pleasant and Riddles lakes, these species have a competitive edge over other species that cannot directly utilize nutrients from the water column.

Pleasant and Riddles lakes exhibit elevated nutrient concentrations greater than those nutrient concentrations observed in many other lakes in the region. The lakes' limited diversity in regards to their rooted plant communities are a reflection of these high nutrient levels. For example, regional lakes with lower, (but still in excess of the Indiana average), total phosphorus levels, such as Silver Lake (Kosciusko County), Ridinger Lake (Kosciusko County), Robinson Lake (Whitley County), Smalley Lake (Kosciusko County), and the Four Lakes (Cook, Holem, Kreighbaum, and Mill Pond lakes, Marshall County), possess similar numbers of submerged species compared to Pleasant and Riddles lakes (JFNew, 1999; JFNew, 2004a; JFNew, 2004b; JFNew, 2005). Additionally, in lakes with high total phosphorus concentrations, such as Smalley, Ridinger, and Robinson lakes, species tolerant of eutrophic water such as Eurasian watermilfoil, Sago pondweed, and coontail tend to dominate the rooted plant communities to the exclusion of species that are more sensitive to eutrophic conditions. In contrast, lakes with more moderate nutrient levels, like Big Chapman Lake in Kosciusko County (JFNew, 2000) exhibit higher quality plant communities. For example, Big Chapman Lake exhibits good species richness and dominant species include species such as large-leaf pondweed which is less tolerant of eutrophic conditions (JFNew, 2000; Chapman Lake Conservation Association et al., unpublished data; JFNew, 2005 unpublished data).

Manipulation of the lakes' plant community either via mechanical (harvesting, boating damage) or chemical (herbicide/algicide applications) means can impact the surviving plant community. For example, emergent vegetation filters runoff from adjacent areas and removal of emergent vegetation eliminates this function. The loss of this function may lead to an increase in nutrient and sediment concentration in the area of lake in front of developed shoreline. An increase in nutrient and sediment concentration can, in turn, shift the submerged plant community from a balance community to one dominated by species tolerant of eutrophic water conditions.

4.6.4 Historical Plant Surveys

Changes in a lake's rooted plant communities over time can illustrate unseen chemical changes in the lake. Unfortunately, limited data detailing Pleasant Lake's historical rooted plant community exists for comparison to the current data. In the past, IDNR fisheries biologists conducted cursory vegetation surveys as a part of their general fisheries surveys. Species lists were recorded during the 1964, 1975, 1985, 1988, and 2003 assessments of Riddles Lake (Schnicke, 1964; Peterson, 1975; Dexter, 1986; Robertson, 1988; Price, 2004b) and the 1977, 1978, 1986, and 2003 assessments of Pleasant Lake (Armstrong, 1978; Robertson, 1979, 1987; Price, 2004a).

Riddles Lake

Historical studies recorded many of the same species that currently dominate Riddles Lake also dominated Riddles Lake in recent history. In 1964, Schnicke noted that spatterdock and white water lily were the most common emergent species and coontail was the dominant submerged species growing within Riddles Lake. The rooted floating species formed an almost contiguous circle around the shoreline of the lake. Submerged species were found only to a depth of 4 feet (1.2 m). Sago pondweed, curly-leaf pondweed, and narrow leaf pondweed were the only other submerged species identified by Schnicke (1966). In total, seven emergent and rooted floating species were documented during the 1964 fisheries survey. These include spatterdock, white water lily, pickerel weed, arrow head, cattail, river bulrush, and swamp loosestrife. Subsequent surveys indicate that similar species dominated the plant community, but note that although plant growth was heavy, it did not reach nuisance levels or restrict access to the lake (Peterson, 1975). In 1985, Robertson (1986) noted the presence of the exotic species, purple loosestrife; however, the remainder of the plant community remained very similar to that observed and documented by previous fisheries biologists. The same species were observed during the 1987 assessment (Robertson, 1988). In 2003, Price (2004b) noted the present of coontail to a depth of 6.75 feet (2 m) and Eurasian watermilfoil to a depth of 5 feet (1.5 m). In total, four submerged species, including coontail, Eurasian watermilfoil, leafy pondweed, and common water weed; five floating species, white water lily, spatterdock, filamentous algae, watermeal, and duckweed; and one emergent species, pickerel weed, were documented in Riddles Lake. During the Tier II assessment completed by IDNR Fisheries Biologist, coontail was present at 82% of the sties, while Eurasian watermilfoil and leafy pondweed were present at 20.5 and 15.4% of the sites (Pearson, 2004). Coontail was also the densest of the four species observed accounting for 40 to 60% of the plants present within the lake (Pearson, 2004).

The biggest difference between the current study of Riddles Lake's plant community and the historical studies is the variation in the diversity of submerged species and in the overall species richness. During the previous surveys, the IDNR observed a total of 18 plant species, 6 of which were submerged species. The maximum number of species observed within Riddles Lake occurred during the initial 1964 assessment where Schnicke (1964) documented the presence of 11 species. The current survey reports the presence of 40 species (7 submerged) within Riddles Lake. A difference in survey methodology is likely the reason for the observed difference in species richness rather than an actual increase in the number of plant species in Riddles Lake. Future IDNR fisheries surveys will likely be more detailed in scope than the historic surveys. These future IDNR fisheries surveys should be compared to the results of the rooted plant survey detailed in this report to document any of the changes described above.

Pleasant Lake

Like Riddles Lake, historical studies conducted in Pleasant Lake indicate that many of the same species that currently dominate Pleasant Lake also dominated Pleasant Lake in recent history. The

1977 IDNR Division of Fish and Wildlife fisheries surveys of the lake noted that milfoil and curly-leaf pondweed each covered 30% of Pleasant Lake, while water lily and coontail covered an additional 20 and 10%, respectively. Arrowhead, duckweed, and water willow were also noted for their presence (Armstrong, 1977). Data from the 1978 survey indicate that the same species were present in similar densities as those observed in 1976. Milfoil, purple loosestrife, cattails, spatterdock, coontail, and duckweed were noted for their presence during the 1986 assessment (Robertson, 1987). In 2003, Price (2004a) added arrow arum, humped bladderwort, leafy pondweed, and watermeal to the list of species observed in Pleasant Lake. These same species were present in Pleasant Lake's plant community during the current assessment.

The biggest differences between the current study of Pleasant Lake's plant community and the historical study is the variation in the diversity of submerged species and in the overall species richness. During the previous four surveys, a total of 15 species were observed. The most were identified during the 2002 assessment, which documented the presence of 10 species. The current survey reports the presence of 26 species within Pleasant Lake. A difference in survey methodology is likely the reason for the observed difference in species richness rather than an actual increase in the number of plant species in Pleasant Lake. Future IDNR fisheries surveys will likely be more detailed in scope than the historic surveys. These future IDNR fisheries surveys should be compared to the results of the rooted plant survey detailed in this report for the current assessment to document any of the changes described above.

4.6.5 Nuisance and Exotic Plants

Although they have not yet reached the levels observed on many other regional lakes, several nuisance and/or exotic aquatic plant species grow in Pleasant and Riddles lakes. As nuisance species, these species will continue to proliferate if unmanaged. (Additionally, it is likely that the watershed supports many terrestrial nuisance species plant species, but this discussion will focus on the aquatic nuisance species.) The plant survey revealed the presence of two submerged, aggressive exotics: Eurasian watermilfoil and curly leaf pondweed. The lakes also support two emergent exotic plant species: purple loosestrife and reed canary grass. As nuisance species, these species have the potential to proliferate if left unmanaged, so lake residents and visitors must treat these species as a threat to the lakes' health. It is possible that these or other exotic species could exist within the thick emergent portions of the rooted plant community near the east and west ends of the lake but were not observed during this survey.

The presence of Eurasian watermilfoil in the two lakes is of concern, but it is not uncommon for lakes in northern Indiana. Eurasian watermilfoil is an aggressive, non-native species. It often grows in dense mats excluding the establishment of other plants. For example, once the plant reaches the water's surface, it will continue growing horizontally across the water's surface. This growth pattern has the potential to shade other submerged species preventing their growth and establishment. In addition, Eurasian watermilfoil does not provide the same habitat potential for aquatic fauna as many native pondweeds. Its leaflets serve as poor substrate for aquatic insect larva, the primary food source of many panfish (Cheruvelil et al., 2002).

Depending upon water chemistry curly leaf pondweed can be less aggressive than Eurasian watermilfoil. Despite this, its presence in the lake is still of concern. Like many exotics, curly leaf pondweed gains a competitive advantage over native submerged species by sprouting early in the year. The species can do this because it is very tolerant of cooler water temperature compared to many of the native submerged species. Curly leaf pondweed experiences a die back during early to mid summer. This die back can degrade water quality by releasing nutrients into the water column and increasing the biological oxygen demand.

Purple loosestrife is an aggressive, exotic species introduced into this country from Eurasia for use as an ornamental garden plant. Like Eurasian watermilfoil, purple loosestrife has the potential to dominate habitats, in this case wetland and shoreline communities, excluding native plants. The stiff, woody composition of purple loosestrife makes it a poor food source substitute for many of the native emergents it replaces. In addition, the loss of diversity that occurs as purple loosestrife takes over plant communities lowers the wetland and shoreline habitat quality for waterfowl, fishes, and aquatic insects.

Like purple loosestrife, reed canary grass is native to Eurasia. Farmers used (and many likely still use) the species for erosion control along ditch banks or as marsh hay. The species escaped via ditches and has spread to many of the wetlands in the area. Swink and Wilhelm (1994) indicate that reed canary grass commonly occurs at the toe of the upland slope around a wetland. Reed canary grass was often observed above the ordinary high water mark around Pleasant and Riddles lakes. Like other nuisance species, reed canary grass forms a monoculture mat excluding native wetland/shoreline plants. This limits a wetland's or shoreline's diversity ultimately impacting the habitat's functions.

The presence of Eurasian watermilfoil, curly leaf pondweed, and other exotics is typical in northern Indiana lakes. Of the lakes surveyed by aquatic control consultants and IDNR Fisheries Biologists, nearly every lake supported at least one exotic species (White, 1998a). In fact, White (1998a) notes the absence of exotics in only seven lakes in the 15 northern counties in Indiana. These 15 counties include all of the counties in northeastern Indiana where most of Indiana's natural lakes are located. Of the northern lakes receiving permission to treat aquatic plants in 1998, Eurasian watermilfoil was listed as the primary target in those permits (White, 1998b). Despite the ubiquitous presence of nuisance species, lakeshore property owners and watershed stakeholders should continue management efforts to limit nuisance species populations. Management options are discussed in the Management section of this report.

4.7 Fisheries

Pleasant and Riddles lakes share very similar fisheries due to their proximity and connection to one another. Fish are able to migrate freely in each of the lakes, which in some ways, act more like sub-basins within one lake rather than two separate lakes.

4.7.1 Riddles Lake

The Riddles Lake fishery has historically seen drastic changes in its fish community since the Indiana Department of Natural Resources first surveyed the lake in 1964. Poor water quality coupled with the introduction of gizzard shad can both be attributed to theses changes. Despite this, Riddles Lake continues to support a fairly diverse fishery. A total of 24 species representing 9 families have been collected from the lake during the IDNR surveys (Appendix J).

The following paragraphs provide a brief summary of the IDNR fishery management survey findings for each given survey year. A list of the IDNR reports used in the following summaries can be found in the literature cited. When reviewing the summaries below, and to some extent the IDNR reports themselves, it is important for the reader to understand that the collection methodologies and procedures used by the IDNR have changed over time. Therefore, any information below should be viewed for trends over time rather than direct comparisons from study year to year. In 2001, the IDNR addressed this by adopting a set of standardized sampling protocol for future studies.

The IDNR first surveyed Riddles Lake in 1964 in response to angler reports of poor fishing following a major fish kill during the winter of 1961 to 1962 (Schnicke, 1966). The IDNR found that a number of fish species were affected by the winter kill including: largemouth bass, black crappie, yellow perch, and bluegill. Perhaps hardest hit was the Riddles Lake bluegill population. Scale samples taken by the IDNR to determine fish age supported angler reports of poor fishing. The winter kill had eliminated many of the older, larger bluegill which typically supports a lake's sport harvest. The winter kill also negatively affected bluegill spawning in the spring of 1962. However, the 1964 IDNR survey revealed that the bluegill population had already begun to show signs of recovery by 1963 (Peterson, 1975).

The winter fish kill can likely be attributed to poor water quality. Although no water quality data was taken immediately after the fish kill during the winter of 1961 to 1962, the IDNR documented dissolved oxygen levels of 4.1 mg/L or less throughout the water column during the 1964 survey. Indiana Administrative Code (IAC 2-1-6) requires that dissolved oxygen average at least 5 mg/L per calendar day and be greater than 4 mg/L during any single assessment (IAC, 2000). The reason for this standard is that many fish species require dissolved oxygen levels of 5 mg/L or greater to survive. This is especially true for gamefish. It is a relatively safe assumption that the winter kill was a result of low dissolved oxygen levels.

Following the 1964 survey, the IDNR conducted two closely spaced fishery surveys on Riddles Lake in 1974 and 1976 (Peterson, 1975; Peterson, 1977). In 1974, the IDNR documented that gizzard shad had become the most dominant fish found in Riddles Lake, representing nearly 48% of the fish collected as compared to less than 1% in 1964 (Figure 65). (Gizzard shad numbers may have been much higher prior to the 1964 survey. However, it is unclear at what levels in which they existed. The 1964 IDNR report simply stated that large numbers were reportedly killed during the winter kill event (Schnicke, 1966).) Bluegill populations dropped from a relative abundance of nearly 33% in 1964 to 20% in 1974 (Figure 65; Schnicke, 1966; Peterson, 1975). Bluegill growth rates had also dropped below average indicating possible competition with gizzard shad for valuable food resources. Gizzard shad are known to compete with larval bluegill for plankton, an important food resource for young sunfish species (Aday et al., 2003). The IDNR recommended chemical treatment of all four lakes within the Heston Ditch Chain (Moon, Pleasant, Dipper, and Riddles lakes) in 1974 to selectively remove gizzard shad and subsequent stocking of largemouth bass (Peterson, 1975).

The IDNR surveyed Riddles Lake in 1976 following the chemical treatment and stocking of largemouth bass fingerlings in the fall of 1975 (Peterson, 1977). The IDNR found that gizzard shad still dominated the Riddles Lake fishery, however, gizzard shad relative abundance decreased from 48.0% in 1974 to 29.3% in 1976 (Figure 65). Despite the reduction in gizzard shad relative abundance, bluegill relative abundance continued to decline from 19.6% in 1974 to 15.7% in 1976 (Figure 62; Peterson, 1977). However, bluegill growth rates and condition factor were found to be above average. This was likely due to reduced competition for food resources. Largemouth bass relative abundance showed a slight increase from 3.4 % in 1974 to 10.0% in 1976 (Figure 65). Largemouth bass relative abundance has remained fairly consistent among survey years (Figure 65; Schnicke, 1966; Peterson, 1975 and 1977).

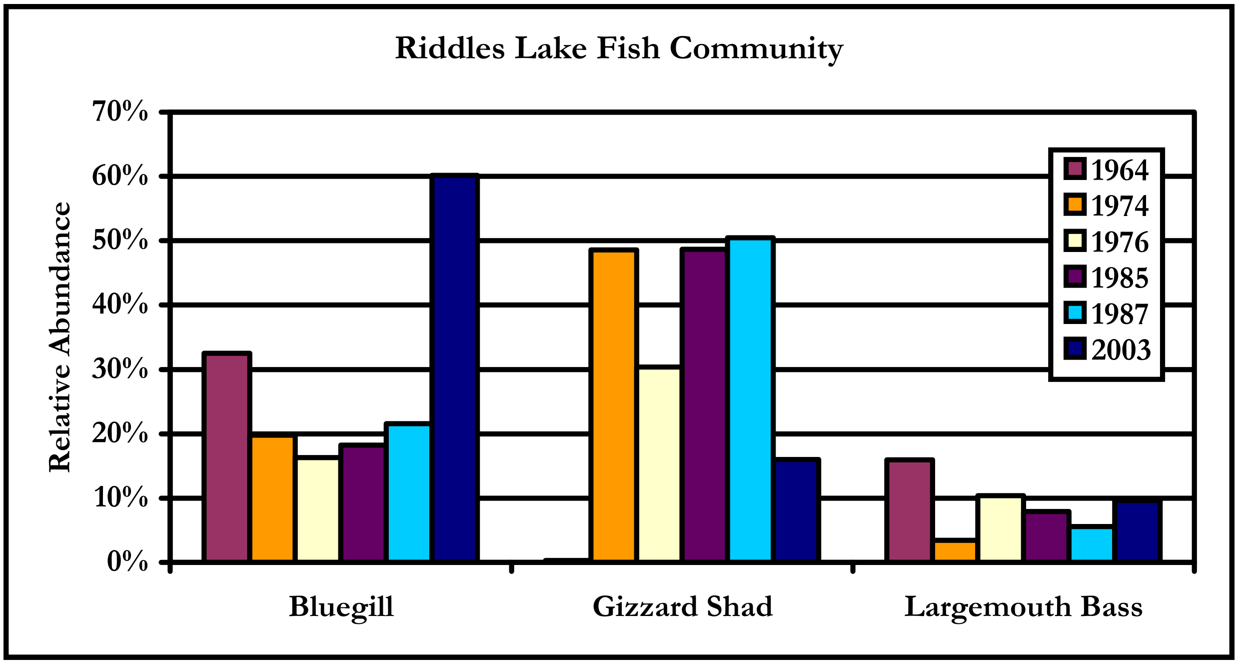

Figure 65. Relative abundance of bluegill, gizzard shad and largemouth bass in Riddles by IDNR survey year.

The IDNR once again conducted two closely spaced surveys on Riddles Lake in 1985 and 1987 (Dexter, 1986; Robertson, 1988). Survey results from both years showed that gizzard shad remained the most abundant fish species accounting for an average of 49% of the relative abundance, in the lake. Bluegill growth rates also continued to be above average for the region through Age III+. Largemouth bass, however, showed a significant increase in electrofishing catch per unit effort (CPUE; No. of fish collected per hour electrofishing) from 9/hr in 1974 to 68/hr in 1985. The IDNR considered largemouth growth rates to be above average. The success of both the bluegill and largemouth bass populations may have been linked to the apparent spawning failure of gizzard shad in 1984. It was believed that tiger musky that were stocked in nearby Pleasant Lake would migrate into Riddles Lake to help further reduce gizzard shad populations (Dexter, 1986). Additionally, the IDNR recommended stocking hybrid striped bass at a rate of 10/ac to prey upon gizzard shad (Robertson, 1988).

As recommended, hybrid striped bass were first stocked in 1989 and continued to be stocked by the IDNR until 1991 (Robertson, 1992). Further stockings, however, were discontinued when no hybrids were collected during follow up evaluations (Robertson, 1992). Despite the failure of the hybrid striper and earlier tiger musky stockings, gizzard shad showed a drastic decline in relative abundance from 50.0% in 1987 to 15.7 % in 2003 (Figure 65; Price, 2004b). No explanation for the decline in gizzard shad numbers was given in the 2004 IDNR report (Price, 2004b). Although, the gizzard shad length frequency data from 2003 may indicate a spawning failure or poor recruitment in 2002 and possibly 2001 (Price, 2004b). In 1996, Walleye were stocked for the first time by the Lakeville Conservation Club and have been stocked annually except in 2002. In 2003 walleye were sampled ranging from 10.2 – 22.2 inches. Bluegill was the most abundant species by number in the lake with a relative abundance of 59.1% for the first time since the 1964 survey (Figure 65; Schnicke, 1966; Price, 2004b)). Bluegill growth continued to be good. Largemouth bass were the second most abundant gamefish, next to bluegill, in Riddles Lake with a relative abundance of 9.5% (Figure 65). Their growth for that time period was also considered good.

Proportional stock density (PSD) is a fishery statistic used to evaluate the abundance and size structure of a fish species (Anderson and Neumann, 1996). Values can range between 0 and 100 with a specific range for a given species representing a balanced population. Bluegill PSD in 2003 was 32.9, representing a population in balance. Largemouth bass PSD in 2003 was 75.8 which is indicative of a population shifted slightly towards larger (>12 inches) individuals.

Gizzard shad are known to have direct and indirect impacts to a lake's fishery. Aday et al. (2003) found that bluegill exhibited reduced growth rates in lakes that contained gizzard shad. Gizzard shad consume large quantities of zooplankton and are capable of drastically altering the plankton community (Dettmers and Stein, 1992). Since gizzard shad spawn earlier than most sport fish species, they are capable of removing most of the zooplankton before sport fish larvae hatch, resulting in starvation of young sport fish species and subsequent poor recruitment (Schoenung, 2003). Additionally, gizzard shad quickly grow beyond a size at which most predators, such as largemouth bass, can utilize them for forage (Garvey and Stein, 1997). This in turn can lead to a reduction in largemouth bass growth and recruitment. A reduction in largemouth bass numbers can subsequently result in an increase of gizzard shad numbers the following year. Often this feedback loop continues until a significant event such as a severe winter reduces gizzard shad populations. At least two of these reductions have occurred as evident by the 1964 and 2003 surveys (Figure 65). Each time that a reduction in the gizzard shad population occurred, there was a general improvement in the lake's sport fishery.

4.7.2 Pleasant Lake

Pleasant Lake was first surveyed by the IDNR in 1972 with the most recent IDNR survey occurring in 2003. A total of 23 fish species representing 10 families have been historically collected from Pleasant Lake (Appendix J). Due to their direct connection to one another, many of the fish species found in Riddles Lake can also be found in Pleasant Lake (Appendix J).

As noted above, the following paragraphs provide a brief summary of the IDNR fishery management survey findings for each given survey year. A list of the IDNR reports used in the following summaries can be found in the literature cited. When reviewing the summaries below, and to some extent the IDNR reports themselves, it is important for the reader to understand that the collection methodologies and procedures used by the IDNR have changed over time. Therefore, any information below should be viewed for trends over time rather than direct comparisons from study year to year. In 2001, the IDNR addressed this by adopting a set of standardized sampling protocol for future studies.

The IDNR first surveyed Pleasant Lake in 1972 (Peterson, 1973). During this electrofishing survey, bluegill was the most abundant species by number followed by gizzard shad. Together these two species represented nearly 85% of the total catch (Figure 66). Largemouth bass was the third must abundant species by number, however, only two individuals were collected. Both bluegill and largemouth bass growth rates were considered average.

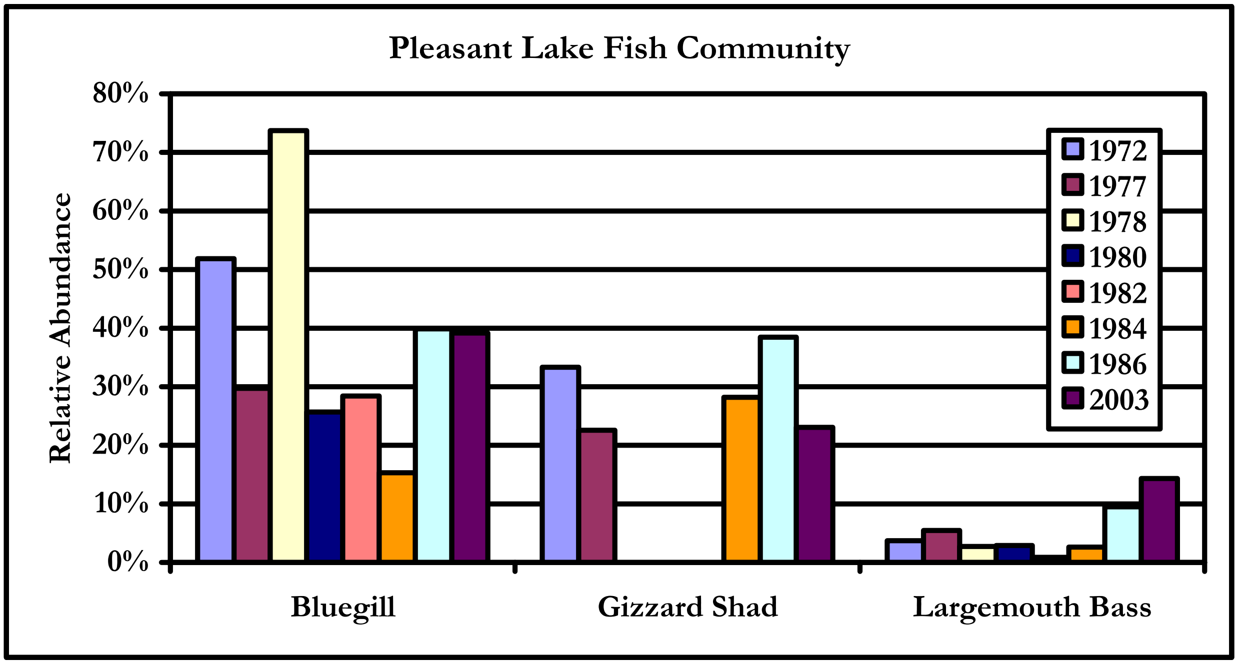

Figure 66. Relative abundance of bluegill, gizzard shad and largemouth bass in Pleasant Lake by IDNR survey year.

Pleasant Lake was next surveyed in 1977 followed by several closely spaced surveys (two years on average) in the late 1970's to mid 1980's (Figure 66 and Appendix J; Armstrong, 1977; Robertson, 1979; Robertson, 1986). As noted above in the Riddles Lake section, the IDNR conducted a chemical treatment of all four lakes within the Heston Ditch Chain (Moon, Pleasant, Dipper, Riddles) in 1975 to selectively remove gizzard shad. Effective gizzard shad control was observed following the 1975 treatment up until the 1984 survey because no gizzard shad were collected in the 1978, 1980, and 1982 surveys (Figure 66). Gizzard shad populations rebounded in 1984 and 1986 representing 28.2% and 38.5% of the total catch, respectively (Figure 66). Gizzard shad populations declined again during the 2003 survey to 23.1% of the total catch (Price, 2004a). The rebound of gizzard shad populations after selective chemical treatment in 1975 can likely be attributed to recolonization from within the watershed.

Bluegill have been the one of the most dominant fish by numbers in Pleasant Lake with relative abundances averaging 38.0% over eight survey years and ranging from 15.3% in 1984 to 73.7% in 1978 (Figure 66). Bluegill PSD in 2003 was 60.2 which represent a population in balance. Growth rates of bluegill have typically been average for the region during each survey year with the exception of 2003. A possible explanation for the decrease in bluegill growth rates may be attributed to competition with gizzard shad for food resources as noted above in the Riddles Lake section.

Largemouth bass, the major predator found in Pleasant Lake, has displayed fairly stable populations from 1972 up until the 1986 survey. Largemouth bass represented nearly 3% of the total catch by numbers during that time period (Figure 66). In 1986, largemouth bass relative abundance increased nearly three times to 9.5% (Robertson, 1987). Largemouth bass relative abundance continued to increase between 1986 and 2003 to 14.3% (Robertson, 1987; Price, 2004a). For the most part, over this time period largemouth bass growth rates have been considered average for the region. Largemouth bass PSD in 2003 was 87.2 which represents a population disproportionately shifted toward larger (>12 inches) individuals. A decline in growth rates was noted in the 2003 survey. The IDNR believes this decline in growth rates may be attributed to a combination of factors including intraspecific competition for food resources, limited harvest, or young-of-the-year mortality associated with gizzard shad forage competition. The IDNR has recommended that a creel survey be conducted on Pleasant and Riddles Lake to provide further insight on the situation.

5.0 MODELING

5.1 Water Budget

Inputs of water to the watershed lakes are limited to:

1. direct precipitation to the lake
2. discharge from the intermittent inlet streams
3. sheet runoff from land immediately adjacent to the lake
4. groundwater

Water leaves the lake system from:

1. discharge from the individual lake's outlet channel
2. evaporation
3. groundwater

There are no discharge gauges in the watershed to measure water inputs and the limited scope of this study did not allow us to quantitatively determine annual water inputs or outputs. Therefore, the water budgets for Pleasant and Riddles lakes were estimated from other records.

- Direct precipitation to the lake was calculated from mean annual precipitation falling directly on the lakes' surface.
- Runoff from the lakes' watershed was estimated by applying runoff coefficients. A runoff coefficient refers to the percentage of precipitation that occurs as surface runoff, as opposed to that which soaks into the ground. Runoff coefficients may be estimated by comparing discharge from a nearby gauged watershed of similar land and topographic features, to the total amount of precipitation falling on that watershed. The nearest gauged watershed is a U.S.G.S. gauging station on the Yellow River in Plymouth, Indiana (Morlock et al., 2004). The 56-year (1949–2004) mean annual discharge for this watershed is 269 cubic feet per second. With mean annual precipitation of 36.78 inches (93.4 cm) (Smallwood, 1980), this means that on average, 33.8% of the rainfall falling on this watershed runs off on the land surface.
- No groundwater records exist for the lakes, so it was assumed that groundwater inputs equal outputs or groundwater effects are insignificant when compared to surface water impacts. It is unlikely that the latter is true for these lakes. However, since no groundwater records for the lake exist we must assume that groundwater inputs equal outputs.

Evaporation losses were estimated by applying evaporation rate data to the lake. Evaporation rates are determined at six sites around Indiana by the National Oceanic and Atmospheric Administration (NOAA). The nearest site to Pleasant and Riddles lakes is located in Valparaiso, Indiana. Annual evaporation from a 'standard pan' at the Valparaiso site averages 28.05 inches (71.2 cm) per year. Because evaporation from the standard pan overestimates evaporation from a lake by about 30%, the evaporation rate was corrected by this percentage, yielding an estimated evaporation rate from the lake surface of 19.95 inches (50.7 cm) per year. Multiplying this rate times the surface area of each lake yields an estimated volume of evaporative water loss from Pleasant and Riddles lakes.

The water budgets for Pleasant, Fites, and Riddles lakes are based on the assumptions discussed above. (The water budget calculations are shown in Appendix K.) When the volume of water flowing out of a lake is divided by the lake's volume the result is known as the lake's *hydraulic residence time*. The hydraulic residence times for Pleasant, Fites, and Riddles lakes range from only 29.2 days (0.08 years) in Riddles Lake to 40 days (0.11 years) in Pleasant Lake (Table 53). (A hydraulic residence time could not be calculated for Fites Lake as the volume of the water body is not known.) This means that on average, water entering the Pleasant Lake stays in the lake for only 40 days before it leaves. This hydraulic flushing rate is extremely rapid for lakes in this part of the country. In a study of 95 north temperate lakes in the U.S., the mean hydraulic residence time for the lakes was 2.12 years (Reckhow and Simpson, 1980). The short hydraulic residence times for Pleasant and Riddles lakes are due to their very large watersheds. There are approximately 192 acres (77.7 ha) of watershed draining into each acre of Pleasant Lake and approximately 99 acres (40.1 ha) of watershed draining into each acre of Riddles Lake. Most glacial lakes have a watershed area to lake surface area ratio of around 10:1. Both Pleasant and Riddles lakes' ratios are more typical of reservoirs, where the watershed area to reservoir surface area typically ranges between 100:1 and 300:1 (Vant, 1987).

Table 53. Water budget summaries for Pleasant, Fites, and Riddles lakes.

Lake	Volume (V, in acre-ft)	Discharge (Q) (in acre-feet per yr)	Residence Time (V/Q) (in years)
Pleasant	663	5,855	0.08
Fites	--	1,212	--
Riddles	624	8,166	0.11

As previously noted, residence time estimates can be used to help guide management of the lakes. In general, lakes possessing long residence times often benefit from in-lake management techniques, while lakes possessing short residence times benefit from watershed management techniques. In lakes with short residence time, such as such as Pleasant and Riddles lakes, water is continuously moving through the lake. Thus, the lakes with short residence times would have good water quality if the water entering these lakes is clean. Conversely, water stays in lakes with long residence time for a longer period of time. As a consequence, internal processes, such as internal phosphorus release from the lake's sediments, can have a larger impact on water quality than the condition of the incoming surface water.

The interconnectedness of these lakes clearly complicates the general rule described above. Riddles Lake may have a relatively short hydraulic residence time, but much of the water coming into Riddles Lake comes from Pleasant Lake which is located upstream of Riddles Lake. As a consequence, internal processes that occur in Pleasant Lake affects the water quality of Riddles Lake. These factors must be considered when deciding on management strategies.

5.2 Phosphorus Budget

Since phosphorus is a limiting nutrient in lakes and because it is the easier of the two main nutrients (phosphorus and nitrogen) required for plant and algal growth to control (Lee and Jones-Lee, 1998), a phosphorus model was used to estimate the dynamics of this important nutrient in Pleasant, Fites, and Riddles lakes. With its role as the limiting nutrient, phosphorus should be the target of management activities to lower the biological productivity of these lakes.

The limited scope of this study did not allow for the determination of phosphorus inputs and outputs outright. Therefore, a standard phosphorus model was utilized to estimate the phosphorus budget. Reckhow et al. (1979) compiled phosphorus loss rates from various land use activities as determined by a number of different studies, and from this, they calculated phosphorus export coefficients for various land uses. Phosphorus export coefficients are expressed as kilograms of phosphorus lost per hectare of land per year. Table 54 shows the phosphorus export coefficients developed by Reckhow and Simpson (1980).

Table 54. Phosphorus export coefficients (units are kg/hectare except the septic category, which are kg/capita-yr).

Estimate Range	Agriculture	Forest	Precipitation	Urban	Septic
High	3.0	0.45	0.6	5.0	1.8
Mid	0.40-1.70	0.15-0.30	0.20-0.50	0.80-3.0	0.4-0.9
Low	0.10	0.2	0.15	0.50	0.3

Source: Reckhow and Simpson, 1980.

To obtain an annual estimate of the phosphorus exported to Pleasant, Fites, and Riddles lakes from the lakes' watershed(s), the export coefficient for a particular land use was multiplied by the area of land in that land use category. Mid-range estimates of phosphorus export coefficient values for all watershed land uses (Table 9) were used in this calculation.

Direct phosphorus input via precipitation to the lakes was estimated by multiplying mean annual precipitation in St. Joseph County (0.9 m/yr) times the surface area of the lake times a typical phosphorus concentration in Indiana precipitation (0.03 mg/L). For septic system inputs, the number of permanent homes on each lake was multiplied times an average of 3 residents per home to calculate per capita years. Using a mid-range phosphorus export of 0.5 kg/capita-yr and a soil retention coefficient of 0.75 (this assumes that the drain field retains 75% of the phosphorus applied to it), phosphorus export from septic systems was calculated. For temporary residences, an average of 6 months per year was used to calculate septic system inputs. Likewise, for seasonal residences, 3 months per year was utilized.

Because these lakes are part of a chain and drain into each other, the amount of phosphorus loading entering Riddles Lake from the Pleasant Lake outlet was also estimated. This was calculated by multiplying the lake discharge from Appendix K Table 2 by the mean whole lake total phosphorus concentration. A volume-weighted mean phosphorus concentration would be more suitable to use for this; however, there is no bathymetric data available for Pleasant Lake; therefore, the volumes of the epilimnion and hypolimnion could not be determined.

Adding the phosphorus export loads from the watershed, septic systems, and precipitation yielded an estimated 2,202 kg of phosphorus loading to Pleasant Lake annually. The greatest estimated source of phosphorus loading to Pleasant Lake is from row crop agriculture which accounts for over 77% of total watershed loading (Table 55). Row crops were estimated to be the greatest watershed source of phosphorus loading to Riddles as well; row crop agriculture accounted for 83.5% of the phosphorus loading to Riddles Lake. Total phosphorus loading to Riddles Lake from Pleasant Lake (2,174 kg/yr) accounted for more of Riddles Lake's phosphorus load than was estimated from direct watershed runoff.

Table 55. Results of the phosphorus loading model.

Watershed	Total P Loading (kg/yr) from watershed sources	% TP Loading from Row Crops	% TP Loading from Forest	% TP Loading from Urban[1]	Total P Loading (kg/yr) from Pleasant Lake discharge
Pleasant	2,206	77	3	8.6	--
Riddles	927	83	2	4.6	2,174

[1]surface runoff only, not including septic system loading

The relationships among the primary parameters that affect a lake's phosphorus concentration were examined employing the widely used Vollenweider (1975) model. Vollenweider's empirical model says that the concentration of phosphorus ([P]) in a lake is proportional to the areal phosphorus loading (L, in g/m^2 lake area - year), and inversely proportional to the product of mean depth ($\bar{z}$) and hydraulic flushing rate (ρ) plus a constant (10):

$$[P] = \frac{L}{10 + \bar{z}\rho}$$

During the July 18, 2005 sampling of Riddles Lake, the mean volume weighted phosphorus concentration in the lake was 0.274 mg/L. It is useful to determine how much phosphorus loading from all sources is required to yield a mean phosphorus concentration of 0.274 mg/L in Riddles Lake. Plugging this mean concentration along with the lake's mean depth and flushing rate into Vollenweider's phosphorus loading model and solving for L yields an areal phosphorus loading rate (mass of phosphorus per unit area of lake) of 11.302 g/m^2-yr. This means that in order to get a mean phosphorus concentration of 0.274 mg/L in Riddles Lake, a total of 11.302 grams of phosphorus must be delivered to each square meter of lake surface area per year.

Total phosphorus loading (L_T) is composed of external phosphorus loading (L_E) from outside Riddles Lake (watershed runoff and precipitation) and internal phosphorus loading (L_I). Since L_T = 11.302 g/m^2-yr and L_E = 10.083 g/m^2-yr (estimated from the watershed loading in Table 56), then internal phosphorus loading (L_I) equals 1.218 g/m^2-yr. Thus, internal loading accounts for about 11% of total phosphorus loading to the water column in Riddles Lake.

Table 56. Areal phosphorus loading rates determined from models.

Lake	Total Areal P Loading (g/m^2 – yr)[1]	External Areal P Loading (g/m^2 – yr)[2]	Internal Areal P Loading (g/m^2 – yr)
Pleasant	22.054	18.801	3.253
Riddles	11.302[3]	10.083[3]	1.218

[1]estimated from Vollenweider's lake response model
[2]estimated from Reckhow's phosphorus export model and precipitation estimates
[3]includes phosphorus discharge from Pleasant Lake

It is important to check this conclusion that internal phosphorus loading accounts for 11% of total phosphorus loading to Riddles Lake with the data collected on July 18, 2005. There is evidence in Riddles Lake that soluble phosphorus is being released from the sediments during periods of anoxia. For example, the concentration of soluble phosphorus in Riddles Lake's hypolimnion on July 18, 2005 was 86 times higher than concentrations in the epilimnion (0.113 mg/L vs. 0.996mg/L). The source of this hypolimnetic total phosphorus is primarily internal loading in most lakes. This internal loading can be a major source of phosphorus in many productive lakes. The modeled estimate of 11% of annual phosphorus loading originating from internal sources seems reasonable given the large difference between summertime epilimnetic and hypolimnetic phosphorus concentrations and the small hypolimnetic volume, which limits the overall mass of phosphorus released from the sediments.

The Vollenwider phosphorus loading model was also used with data from Pleasant Lake. Results for both lakes are compared in Table 57. (Appendix L contains detailed phosphorus modeling spreadsheets for both lakes.) Note that total loading to Riddles Lake includes phosphorus discharge from Pleasant Lake

Table 57. Phosphorus reduction required to achieve acceptable phosphorus loading rate and a mean lake concentration of 0.03 mg/L

Lake	Current Total Areal P Loading (g/m^2-yr)	Acceptable Areal P Loading (g/m^2-yr)	Reduction Needed (kg P/yr and %)
Riddles	11.301	1.238	20,322 (89%)
Pleasant	22.054	2.200	11,168 (90%)

The significance of areal phosphorus loading rates is better illustrated in Figure 67 in which areal phosphorus loading is plotted against the product of mean depth times flushing rate. Overlain on this graph is a line, based on Vollenweider's model, which represent an acceptable loading rate that yields a phosphorus concentration in lake water of 30 µg/L (0.03 mg/L). The areal phosphorus loading rate for each lake is well above the acceptable line.

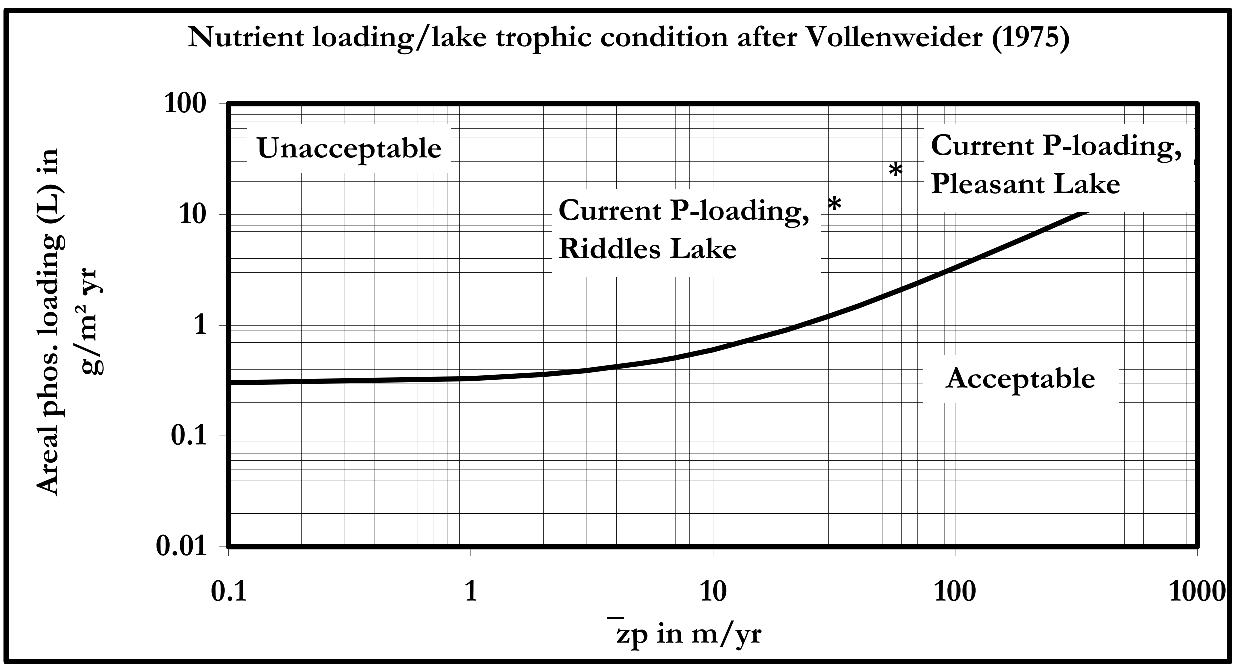

Figure 67. Phosphorus loadings to Riddles (*) and Pleasant (*) lakes compared to acceptable loadings determined from Vollenweider's model. The dark line represents the upper limit for acceptable loading.

This figure can also be used to evaluate management needs. For example, areal phosphorus loading to Riddles Lake would have to be reduced from 11.301 g/m^2-yr to 1.238 g/m^2-yr (the downward vertical intercept with the line) to yield a mean lake water concentration of 0.030 mg/L. This represents a reduction in areal phosphorus loading of 10.063 g/m^2-yr to the lake (89%), which is equivalent to a total phosphorus mass loading reduction 20,322 kg P/yr. Pleasant Lake would require a similarly high reduction in total areal loading in order to achieve a mean lake water concentration of 0.030 mg/l (Table 55).

6.0 MANAGEMENT

The preceding sections of this report detailing Pleasant and Riddles lakes' current condition indicate that the lakes possesses poor water quality in comparison to other lakes in the region and throughout the state. The lakes have poor clarity with a Secchi disk depth of 2.3 feet (0.7 m). Nutrient concentrations are higher than the state medians. The lakes' total phosphorus concentrations place the lakes in the hypereutrophic category based on Carlson's TSI. Much of this phosphorus is in the lakes' hypolimnion where it is not typically accessible to algae. The higher than average nutrient levels present in Pleasant and Riddles lakes result in an elevated productivity levels in both lakes. The lakes' chlorophyll *a* concentrations, Indiana TSI scores, and Secchi disk depths suggest that Pleasant and Riddles lakes are eutrophic in nature.

Watershed drainage plays a large role in the poor water quality observed in Pleasant and Riddles lakes. The large watershed area that drains into Pleasant and Riddles lakes delivers excessive amounts of sediments and nutrients, particularly phosphorus. The lakes' extremely high watershed area to lake area ratios indicate that more than 99 acres of watershed drain to each acre of Riddles Lake and more than 192 acres of Pleasant Lake drain to each acre of Pleasant Lake. These ratios are more than 10 times the typical ratio for glacial lakes (Vant, 1987). (Phosphorus loading to Pleasant and Riddles lakes from their watersheds exceeds permissible rates necessary to maintain good water quality by factors of 10 and 9, respectively.) The phosphorus stimulates plankton growth in the lakes as indicated by the high chlorophyll *a* concentrations. The algae growth and sediment loading result in poor water transparencies in both lakes.

Pleasant and Riddles lakes have historically exhibited poor water quality and recent samplings indicate that water quality remains poor within the lakes. There is also some evidence that this trend may continue into the future. The phosphorus modeling shows that more phosphorus is entering the lakes from the watershed than can be absorbed by the lakes and have them still maintain a moderate level of productivity. Similarly, the lack of oxygen in the lakes' lower levels suggests the rate of photosynthesis (oxygen production) is less than the rate of oxygen consumption. The relatively high concentration of ammonia in Pleasant and Riddles lakes' hypolimnia suggest that decomposition rates may be the primary reason for the oxygen consumption. Likewise, high soluble reactive phosphorus concentrations in the epilimnia indicate that phosphorus release from the sediment is likely occurring within the lakes. Currently, internal phosphorus loading within Pleasant Lake accounts for nearly 15% of the overall phosphorus load to the lake. Based on this evidence, the rate of organic material input to the lake may be exceeding the level that the lake can effectively process without compromising water quality.

Overall, the water quality of Pleasant, Fites, and Riddles lakes is worse than most of Indiana's lakes. All three lakes are highly productive or eutrophic. However, Fites Lake possessed marginally better water quality than that present in Pleasant and Riddles lakes. The Fites Lake watershed is relatively protected by the predominance of forested and wetland land uses within the watershed. The poor water quality present in Fites Lake suggests that soils and natural history may contribute more to water quality within this lake than anthropogenic forces.

The lakes' biological community indicates that the long-term water quality is similar to what is indicated by the water chemistry sampling conducted within the lakes. Riddles Lake supports 40 aquatic plant species, while Pleasant Lake supports only 26 aquatic plant species. In both lakes, a majority of the observed plant species represent the emergent strata; only five submerged species were observed in Pleasant Lake and only seven submerged species were observed in Riddles Lake. Coontail, Eurasian watermilfoil, filamentous algae, spatterdock, and watermeal dominate Pleasant Lake's plant community, while these same species plus pickerel weed and purple loosestrife dominate Riddles Lake's plant community. The presence of several exotic aquatic plant species including Eurasian watermilfoil, curly leaf pondweed, purple loosestrife, and reed canary grass are also of concern to the health of Pleasant and Riddles lakes.

High suspended sediment loads and soluble reactive phosphorus, total phosphorus, and *E. coli* concentrations present in the streams draining the watershed result in degraded stream habitat for macroinvertebrates and fish. All streams possessed poor substrate scores due to these elevated sediment loads. Inadequate riparian vegetated buffers and poor land use practices contribute to this problem. The sediment load in the streams ultimately moves downstream and contributes to the poor water transparency in the lakes. The poor transparency is further exacerbated by elevated soluble reactive and total phosphorus concentrations present in the inlet streams. The concentrations present in the Pleasant and Riddles Lakes watershed streams suggest that both soluble phosphorus from fertilizers and septic waste and particulate phosphorus, which is typically attached to sediments, levels are a concern in the Pleasant and Riddles Lakes watershed. High *E. coli* bacteria levels in the drainage streams are also quite high. The *E. coli* present in the streams can likely be attributed to contamination by human, wildlife, and livestock wastes. This further illustrates the effect of poor septic treatment and agricultural management practices and inadequate streamside vegetated buffers within the watershed.

In total, the problems identified in our analysis of Pleasant, Riddles and Fites lakes that require management address to following issues:
- Oxygen depletion in deeper waters (hypolimnion).
- Phosphorus release from the sediments.
- Excessive nutrient concentrations, especially phosphorus
- Poor water transparency
- Excessive rooted plants in shallow areas
- Inadequate shoreline buffers

Before any management actions are taken, a comprehensive plan that considers the current and best uses of the lakes, and includes input from lake homeowners and lake users alike must be carefully crafted. Critical to this evaluation is a consideration of the 'nature' of the lakes themselves. The following characteristics are common to all of the lakes: 1) extensive shallow areas; 2) extensive rooted aquatic plant growth in these shallow areas; and 3) high nutrient concentrations.

Limnologists have only recently focused on how shallow lakes behave differently than deeper lakes. While Riddles and Fites lakes can be considered shallow throughout their surface area, Pleasant Lake is deeper; however, it does have extensive shallow areas. In shallow lakes with sufficient nutrients, either rooted plants or algae dominate. Rarely does dominance by both plants and algae occur. When rooted plants dominate, they stabilize lake sediments, thus reducing resuspension of sediment nutrients; compete with algae for available nutrients; shade out algae, thereby limiting production; release chemicals that inhibit algae growth; and help improve water transparency. On the other hand, when algae dominate the lake they compete with rooted plants for available nutrients; begin their growth earlier in the spring than rooted plants; through early growth, can shade out rooted plants; are continuously fed in shallow lakes by nutrients resuspended from the sediments by wind, boats or benthic fish (such as carp); and result in poor transparency. A shallow lake may thus have a stable rooted plant community or a stable algae community. A lake may switch from one stable state to another but the switch back is more difficult.

Given these options, lake residents must decide which of the lake conditions is preferable: rooted plant dominance or algal dominance. As it now stands, all of the lakes possess poor Secchi disk transparencies due to fairly dense algal concentrations and high suspended sediment levels. Dense algae are promoted by a) high nutrient concentrations and b) few zooplankton algae grazers due, in part, to high predation by planktivorous fish such as gizzard shad and young or stunted sunfish. High suspended sediments within the lakes are promoted by: a) high watershed runoff rates, b) wind and boat resuspension of the shallow bottom sediments, and c) feeding activities of carp.

If greater transparency is desired, then the following actions can be effective in improving conditions:

- Reduction of sediment loading by diversion of inflow.
- Reduction of sediment loading by installation of either sediment retention basins in the watershed or vegetated filter strips along all inlet ditches and streams
- Reduction of sediment resuspension by elimination of the carp
- Reduction of algae concentrations by phosphorus controls
- Reduction of algae concentrations by increasing zooplankton grazing pressure (i.e., eliminate the planktivorous fish)

To prevent, or at least delay, further degradation of Pleasant, Fites, and Riddles lakes water quality and biological communities, area residents and watershed stakeholders are strongly encouraged to actively manage their lakes and watershed. Management efforts should focus on reducing both external and internal phosphorus loading to the lakes. The lakes' large watershed area to lake area ratio suggests actions taken within the lake's tributaries and throughout the watershed can have a significant impact of the lake's health. Thus management of watershed-wide projects such as wetland restoration, septic system issues, and agricultural Best Management Practices should be prioritized. Bunch and Walters ditches high phosphorus, sediment, and bacteria levels indicate that watershed management techniques that treat these pollutants are also important. Finally, the lakes' relatively short hydraulic residence times means in-lake management, which can affect nutrient cycling, should receive a lower priority. In-lake management techniques should not be ignored; however, watershed based projects will likely provide a greater positive impact to the lakes' water quality. The following paragraphs describe the management techniques recommended for Pleasant and Riddles lakes and their watershed. For the sake of clarity, the techniques are separating into two categories: watershed management techniques and in-lake management techniques.

6.1 Watershed Management

The areas that would benefit most from watershed management techniques are detailed in Figure 68. Watershed management techniques are broken into a few major categories. Specifics about each of these areas are detailed below.

6.1.1 Town of Lakeville Wastewater Treatment Plant Maintenance

The water and sanitary infrastructure for the Town of Lakeville was constructed in the early 1960s. Aging infrastructure, regulatory changes, and current and future development are all putting pressure on the current systems. Based on these concerns, the Town of Lakeville hired Lawson-Fisher Associates (LFA) to complete a Water and Sewer Master Plan (Lawson-Fisher Associates, 2001). The plan was designed to identify necessary capital improvements, determine cost-effective strategies for growth, prepare a prioritized improvement system, and develop a financial strategy for future work. The 10-year planning area utilized by LFA includes much of the Pleasant and Riddles lakes watershed extending north to Osborne Road, west to Maple Road, south to Leeper Road/Rockstroh Road, and east to Kenilworth Road.

The sanitary sewer system was constructed in 1967 and serves the developed portion of the Town of Lakeville. Wastewater is collected and pumped via two pump stations, Pump Station Number 1 (Lake Trail) and Pump Station Number 2 (Patterson Street), to the wastewater treatment facility located on Shidler-Hoffman Ditch east of Lakeville. Pump Station1 collects 95% of the service areas sewage by gravity flow, while Pump Station 2 collects sewage from the remaining 5% of the service area before discharging its collected material to Pump Station 1; therefore, the entirety of the Town of Lakeville's wastewater flows through Pump Station Number 1 (Lawson-Fisher Associates, 2001). Storm water from the Town of Lakeville is collected in a separate collection system.

In 2001, LFA concluded that the wastewater treatment plant was operating below its full capacity and within its permitted guidelines. However, LFA estimated that the treatment plant would be operating at 98% capacity in the near future. This is of concern because several parcels that are currently outside of the town boundaries, and therefore outside the wastewater treatment plant boundaries, are being considered for development and subsequent annexation by the Town of Lakeville. More than 100 housing units are currently under development on the northeast and northwest corners of the town. These areas will be annexed into the town and included on the water and wastewater infrastructural systems. Additional development plans suggest that more than 300 housing units will be added in and around the Town of Lakeville over the next 15 years. All of these units will eventually be connected to the town's infrastructure. This additional growth needs to be accounted for in when determining the best manner to handle wastewater treatment plant maintenance and upkeep issues.

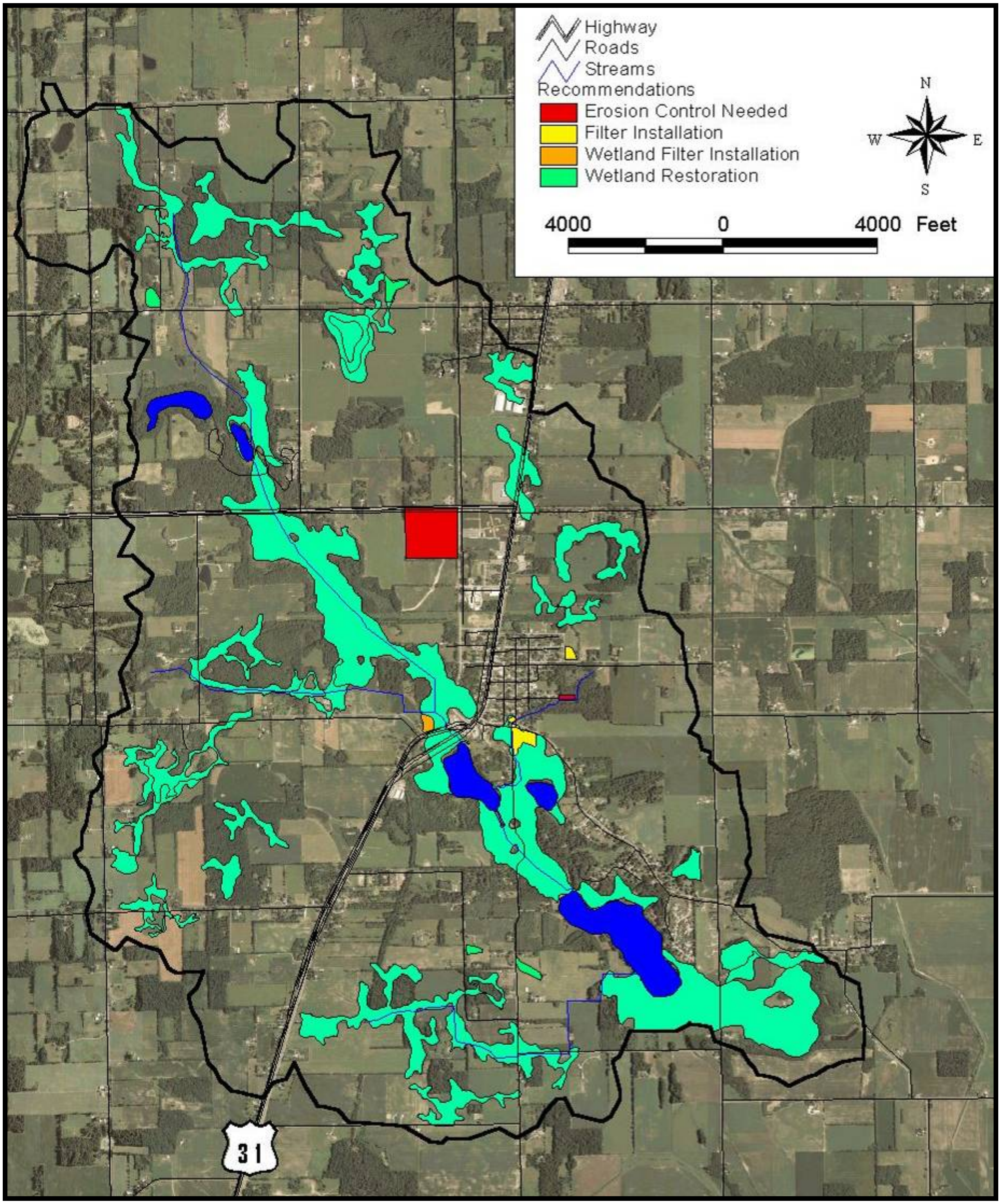

Figure 68. Areas that would benefit from watershed management technique installation.

Of even greater concern are the wastewater overflows that occurred historically and during the completion of this study. The Town of Lakeville's wastewater treatment plant documented two overflows that occurred in January, March, and July of 2005 and in March 2006. The July 2005 overflow occurred at Pump Station Number 1 which is directly adjacent to Bunch Ditch. Evidence of this overflow can be observed in the water quality samples collected from Bunch Ditch at or around the July overflow period. Total Kjeldahl nitrogen, ammonia-nitrogen, soluble reactive and total phosphorus, and *E. coli* concentrations were all elevated during base and storm flow sample collection at the Bunch Ditch sampling site (Table 15). *E. coli* concentrations measured 3,900 colonies/100 mL during base flow collection and 800,000 colonies/100 mL during storm flow collection. These values represent concentrations more than 10 times the Indiana state standard during base flow and more than 246 times the state standard during storm flow. Subsequent sampling of this same stream by the St. Joseph County Health Department yielded an *E. coli* concentration of 50,000 colonies/100 mL which is on par with a wet weather Combined Sewer Overflow concentration (Paula Reinhold, St. Joseph County Health Department, personal communication). The St. Joseph County Health Department continues to investigate the issues associated with the overflow and the plant's infrastructure.

An additional overflow occurred in March 2006. This overflow was documented by the Town of Lakeville and recorded by the Indiana Department of Environmental Management during a routine site investigation. Untreated sewage, toilet paper, and general stormwater flowed out of the overflow pipe and into Bunch Ditch. The overflow lasted for more than 10 hours. The St. Joseph County Health Department continues to investigate the issues associated with these overflows and the plant's infrastructure. The Town of Lakeville has hired a series of contractors to determine locations of leaking infrastructure in poor working conditions. The Town should continue to make every effort to work with the health department to correct wastewater issues and prevent future loading of nutrients and pathogens to Bunch Ditch, and subsequently, Pleasant and Riddles lakes.

6.1.2 Existing Development Issues

While watershed stakeholders can do all they can to support established policies and ordinances, authorized jurisdictions must enforce existing ordinances in order for the ordinances to protect the lakes' ecological health. One area in particular that could use more attention is the enforcement of existing erosion control ordinances. The city, county, and state all have some form of an erosion control ordinance covering many types of projects including but not limited to individual construction projects, subdivision construction, or roadway construction. Two subdivisions are currently under development on the northeast and northwest corners of Lakeville (Figure 68). Both of these developments suffer from lack of erosion control management. The development located on the northeast corner of town is directly adjacent to Bunch Ditch. Special care should be taken to properly install silt fences between the development and Bunch Ditch (Figure 69).

Poor erosion control management was even more prevalent within the development on the northwest corner of Lakeville. The most commonly observed problems were the tracking of sediment from the housing units onto the pavement which then subsequently washes into the closest storm drain (Figure 70) and the lack of adequate protection around storm drains. Figures 70 to 73 detail several storm drains located within the development and adjacent to Mangus Road where storm drains are covered by sediment. Figure 74 documents a catch basin that has already filled with sediment and organic material within this development. Water from these drains eventually reaches Heston Ditch, which then carries the sediments and nutrients into Pleasant Lake. The presence of an erosion control ordinance is not sufficient to prevent this from occurring. A well-funded, active enforcement program must accompany any erosion control ordinance to ensure the protection of the lakes.

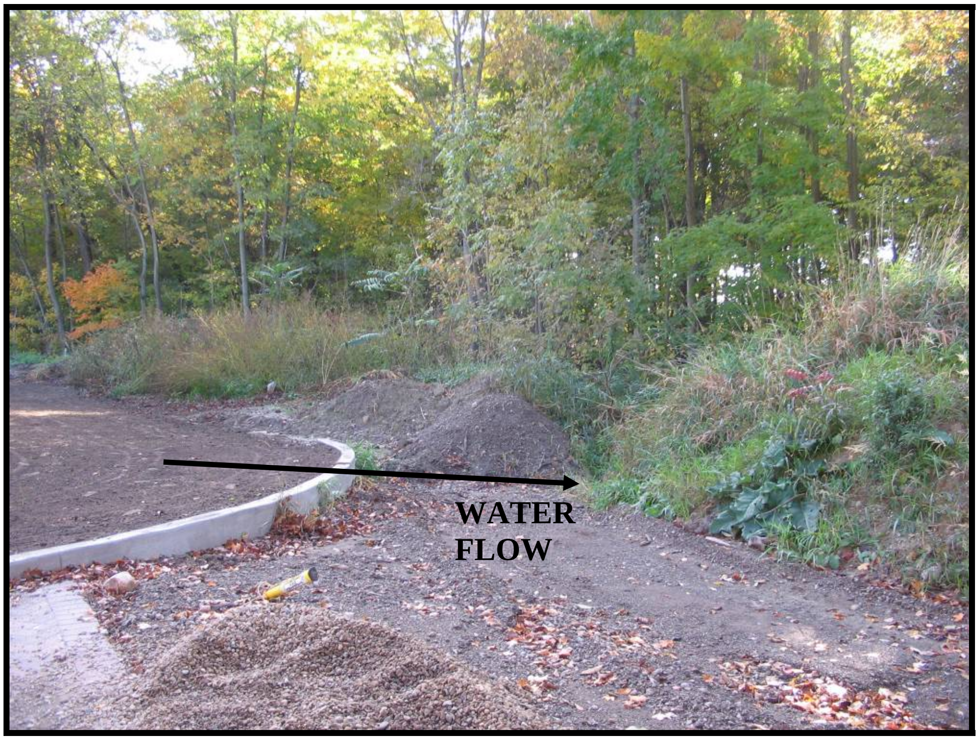

Figure 69. Area that would benefit from silt fence or other erosion control practice installation adjacent to Bunch Ditch. Water runs away from the houses, around the curbing, and through the exposed soil before running unfiltered downhill into Bunch Ditch.

Figure 70. Area where sediment was tracked from the development onto the pavement, then subsequently washed downhill to the nearest storm drain.

Figure 71. Unprotected storm drain covered by sediment from the adjacent development site.

Figure 72. Storm drain with minimal protection. Sediment covers the area in and around the storm drain.

Figure 73. Sediment released from the active construction site reaching the storm drain adjacent to Mangus Road. Water from this drain eventually flows into Pleasant Lake.

Figure 74. The limited stormwater and erosion control practices adjacent to this drain do not adequately provide filtration for sediment and organic material that already fill the drain. This is connected to the same drain documented in Figure 73 (above).

6.1.3 Additional Treatment of Stormwater Runoff

The Town of Lakeville represents the majority of residential and commercial development within the Pleasant and Riddles Lakes watershed. However, other developed areas, such as the Riddles Lake Subdivision, are also sources of urban pollutants. The urban landscape can contribute more pollutants to nearby waterbodies than some agricultural landscapes. The U.S. Environmental Protection Agency's National Urban Runoff Program (USEPA, 1983) results suggest that pollutant runoff rates, including nutrients and suspended solids, will increase as land is converted from agricultural fields to urban landscapes. Reckhow and Simpson (1980) found similar results in their review of studies of nutrient export rates from various landscapes. Bannerman et al. (1993) reported that streets and parking lots release significant amounts of stormwater contaminants. Given the potential for water pollution from typical urban landscapes, watershed stakeholders must also focus on urban watershed management. The following paragraphs describe several urban watershed management techniques and best management practices (BMPs) that are applicable to the Pleasant and Riddles Lakes watershed.

In addition to proper management of the landscape, watershed stakeholders might consider working with the Town of Lakeville to obtain more treatment for stormwater after it enters individual storm drains or after it enters Bunch Ditch. One potential option for providing additional treatment is to restore the field at the southeast of the intersection of Lake Trail and Linden Road to wetland filter habitat and then direct the flow of water from Bunch Ditch into this field (Figure 75). (This area is mapped as a potential wetland filter in Figure 68.) Typical urban stormwater contains high levels of nutrients, sediment, and other pollutants that cause negative impacts to lake ecosystems, and it is likely that stormwater from the Town of Lakeville is no exception. Properly designed wetland filters can remove more than 80% of the total suspended solids and more than 45% of the total phosphorus released to the filter (Winer, 2000). Removal efficiencies will depend upon site conditions and factors related to the structure's design, operation, and maintenance.

Figure 75. Open field adjacent to Bunch Ditch which could be utilized as a wetland filter.

The potential for retrofitting some of the hard surfaces within the Town of Lakeville with stormwater Best Management Practices (BMPs) that promote infiltration should also be investigated. This is especially true for the areas where soils are appropriate for infiltration BMPs. Filtration trenches, sand filters, and biofilters (a variation of sand filters that are planted with native vegetation to allow additional nutrient uptake) provide good treatment for stormwater pollutants. Research (Winer, 2000) suggests these infiltration BMPs are particularly good for treating pollutants of concern in the Pleasant and Riddles lakes watershed, phosphorous and sediment. These BMPs also promote infiltration of stormwater rather than storing it and discharging it at a later time. This simulates the natural hydrology of the watershed by recharging the groundwater with at least a portion of the stormwater rather than sending the whole volume downstream. Unfortunately, these BMPs can be costly and difficult to maintain, factors that should be balanced with the benefits derived from these BMPs.

6.1.4 Individual Property Management

Individual property owners can take several actions to improve Pleasant and Riddles lakes. First, shoreline landowners should consider re-landscaping lakeside properties to protect their lake. Some of the homes on Riddles Lake have maintained turf grass lawns that extend to the lake's edge. Runoff from residential lawns can be very high in phosphorus. In a study on residential areas in Madison, Wisconsin, Bannerman et al. (1993) found extremely high total phosphorus concentrations in stormwater samples from residential lawns. The average phosphorus concentration of runoff water from residential lawns was nearly 100 times the concentration at which algae blooms are expected in lake water. While some dilution occurs as runoff water enters the lake, this source of phosphorus is not insignificant. Other researchers have found similarly high total phosphorus concentrations in lawn runoff water (Steuer et al., 1997).

The ideal way to re-landscape a shoreline is to replant as much of the shoreline as possible with native shoreline species. Even areas where a more natural shoreline is still present along the Pleasant and Riddles lakes could benefit from the installation of a shoreline buffer (Figure 76). Rushes, sedges, pickerel weed, arrowhead, and blue-flag iris are all common species native to northern Indiana lake margins. These species provide an aesthetically attractive, low profile community that will not interfere with views of the lake. Plantings can even occur in front of existing seawalls. Bulrushes and taller emergents are recommended for this. On drier areas, a variety of upland forbs and grasses that do not have the same fertilizer/pesticide maintenance requirements as turf grass may be planted to provide additional filtering of any runoff. Plantings can be arranged so that access to a pier or a portion of the lakefront still exists, but runoff from the property to the lake is minimized. Thus, the lake's overall health improves without interfering with recreational uses of the lake. Henderson et al. (1998) illustrate a variety of landscaping options to achieve water quality and access goals. Appendix M contains a list of potential species that could be planted at the lake's shoreline and further inland to restore the shoreline.

Figure 76. View of the water's edge along Riddles Lake. Native shoreline vegetation has been removed and replaced with turf grass. Although the landowner of this property does not use fertilizer on this particular property, phosphorus input from this area of turf grass is likely much higher than those areas with intact riparian buffers.

Restoring Riddles Lake's shoreline by planting the area with native vegetation will return the functions the shoreline once provided the lake. In addition to filtering runoff, well-vegetated shorelines are less likely to erode, reducing sediment loading to the lake. Well-vegetated shorelines also discourage Canada geese. Canada geese prefer maintained lawns because any predators are clearly visible in lawn areas. Native vegetation is higher in profile than maintained lawns and has the potential to hide predators, increasing the risk for the geese. Wire fences or string lines do little to discourage geese, since these devices do not obscure geese sight line and geese learn to jump wire fences. Unlike concrete or other hard seawalls, vegetated shorelines dampen wave energy, reducing or even eliminating the "rebound" effect seen with hard seawalls. Waves that rebound off hard seawalls continue to stir the lake's bottom sediments, reducing water clarity and impairing the lake's aesthetic appeal. (Residents might also consider replacing concrete seawalls with glacial stone to reduce the "rebound" effect.) Finally, well-vegetated shorelines provide excellent habitat for native waterfowl and other aquatic species.

Exotic species like purple loosestrife and reed canary grass, are present along the lakeshore, on the docks, and within the adjacent lawns of individual residences around Pleasant and Riddles lakes (Figure 77). Both of these species are introduced from Eurasia and spread rapidly through prolific seed production and cultivation. Without individual control, both species can spread along the lakeshore inhibiting boat mooring and individual access to the lake (JFNew, 2005c). (See the Macrophyte Discussion for more information on these plants.) Landowners should replace these plants with native species that provide equal or better quality aesthetics and are more useful to birds, butterflies, and other wildlife as habitat and a food source. Reed canary grass should be replaced with switch grass, Indian grass, or even big blue stem depending on the landowner's desired landscaping (Figure 78). Swamp blazing star, swamp milkweed, cardinal flower, blue-flag iris, or blue lobelia all offer more habitat and aesthetic variety than that offered by purple loosestrife (Figure 79). A mixture of these species will also allow for colorful blooms throughout the growing season.

Figure 77. Purple loosestrife along Riddles Lake's shoreline.

Figure 78. Switch grass (left), big bluestem (center), and Indian grass (right) are some of the grass species suggested for shoreline planting along Pleasant and Riddles lakes.

Figure 79. Some of the forbs suggested for shoreline planting along Pleasant and Riddles lakes are swamp blazing star (top left), swamp milkweed (top center and with bumblebee top right), cardinal flower (bottom left), blue-flag iris (bottom center), and blue lobelia (bottom right).

One specific area of erosion was identified along Pleasant and Riddles lakes shoreline during the plant survey. This area is located along the Lakeville Conservation Club channel (Figure 80). Some stabilization of the area has already been attempted through the use of recycled tires. However, the channel bank continues to erode around the tires. In this particular area, the channel bank should be resloped, and planted with a variety of native vegetation using any number of erosion control products to help establish the vegetation. This area could serve as a demonstration area for the installation of shoreline buffers along the lakeshore and throughout the region.

Figure 80. Bank erosion occurring along the Lakeville Conservation Club channel.

In addition to re-landscaping lakefront property, all lake and watershed property owners should reduce or eliminate the use of fertilizers and pesticides. These lawn and landscape-care products are a source of nutrients and toxins to the lake. Landowners typically apply more fertilizer to lawns and landscaped areas than necessary to achieve the desired results. Plants can only utilize a given amount of nutrients. Nutrients not absorbed by the plants or soil can run into the lake either directly from those residents' lawns along the lake's shoreline or indirectly via storm drains. This simply fertilizes the rooted plants and algae in the lake. At the very minimum, landowners should follow dosing recommendations on product labels and avoid fertilizer/pesticide use within 10 feet of hard surfaces such as roads, driveways, and sidewalks and within 10 to 15 feet of the water's edge. Where possible, natural landscapes should be maintained to eliminate the need for pesticides and fertilizers.

If a landowner considers fertilizer use necessary, the landowner should apply phosphorus-free fertilizers. Most fertilizers contain both nitrogen and phosphorus. However, the soil usually contains enough natural phosphorus to allow for plant growth. As a consequence, fertilizers with only nitrogen work as well as those with both nutrients. The excess phosphorus that cannot be absorbed by the grass or plants can enter the lake, either directly or via storm drains. Landowners can have their soil tested to ensure that their property does indeed have sufficient phosphorus and no additional phosphorus needs to be added. The Purdue University Extension or a local supplier can usually provide information on soil testing.

Shoreline landowners should also avoid depositing lawn waste such as leaves and grass clippings in Pleasant or Riddles lakes or their tributaries as this adds to the nutrient base of the lake. Pet and other animal waste that enters the lake also contributes nutrients and pathogens to it. All of these substances require oxygen to decompose. This increases the demand on the lake. Yard, pet, and animal waste should be placed in residents' solid waste containers to be taken to the landfill rather than leaving the waste on the lawn or piers to decompose.

Each lake property owner and Town of Lakeville resident should investigate local drains, roads, parking areas, driveways, and roof tops. (Figures 81 and 82 documents one of several storm drains located within the Town of Lakeville are currently full of sediment and organic material that will be carried into Pleasant Lake.) Resident surveys conducted on other northern Indiana lakes have indicated that many lakeside houses have local drains of some sort on their properties (JFNew, 2000c; JFNew, 2002). These drains contribute to sediment and nutrient loading and thermal pollution of the lake. Where possible, alternatives to piping the water directly to the lake should be considered. Alternatives include French drains (gravel filled trenches), wetland filters, catch basins, and vegetated overland swales. Residents might also consider the use of rain gardens or rain barrels to treat stormwater on individual lots.

Figure 81. Storm drain located within the Town of Lakeville covered by leaves and filled with sediment and organic material.

Figure 82. Storm drain located within the Town of Lakeville covered by leaves and filled with sediment and organic material.

Individuals should take steps to prevent unnecessary pollutant release from their property. With regard to car maintenance, property owners should clean any automotive fluid (oil, antifreeze, etc.) spills immediately. Driveways and street fronts should be kept clean and free of sediment. Regular hardscape cleaning would help reduce sediment and sediment-attached nutrient loading to the waterbodies in the watershed. Street cleaning would also reduce the loading of heavy metals and other toxicants associated with automobile use. Residents should avoid sweeping driveway silt and debris into storm drains. Rather, any sediment or debris collected during cleaning should be deposited in a solid waste container.

Finally, individual property owners should take steps to minimize the water quality impacts of their on-site waste water treatment systems (i.e. septic systems). Overloaded or leaking septic systems deliver nutrients and other pollutants such as *E. coli* to nearby waterbodies. This can increase the waterbodies' productivity and threaten human health. To address the problems posed by septic systems, properties owners should conduct regular septic tank maintenance. Frequency of septic tanks cleaning depends on the size of the tank and number of persons utilizing it. Jones and Yahner (1994) suggest dividing the size of the septic tank by the product of 100 and the number of persons in the household to determine the frequency of cleaning. For example, if a household of four that does not use a garbage disposal is served by an 800-gallon septic tank, this household should clean its tank every 2 years. (800/(100*4) = 2) Use of a garbage disposal increases solids loading to a septic tank by about 50% so this needs to be considered when calculated cleaning frequency. It is important to distinguish between "cleaning" which means the removal of solids and effluent from the tank and "pumping" which refers to removal of only the liquid effluent from the tank. Where necessary, systems should be upgraded to ensure they can handle any increases in waste stream that have occurred over the years (i.e. modernization of home, increases in residence time, etc.) Water conservation measures such as using low-flow toilets or taking shorter showers will also decrease loading to septic systems.

Those are the minimum steps that should be taken to prevent an increase in pollution from septic systems. Alternatives that actually reduce the waste stream should also be considered. For example, wastewater wetlands typically produce cleaner effluent at the end of a leach field than traditional systems. This is particularly true during the summer months, when plants in such a wetland operate at peak evapotranspiration capacity. Very little effluent leaves the wetlands. This reduction in effluent release corresponds with the peak times for potential algae blooms in the lake. The wetland is working hardest to prevent nutrients from reaching the lake at the exact time when nuisance algae blooms could develop if sufficient nutrients are present. Leach fields of wastewater wetlands are smaller than traditional leach fields making them more attractive on lots where limited space is available. Finally, because of the relative proximity of Pleasant and Riddles lakes to Lakeville, connection to their sanitary sewer system is a possibility, albeit an expensive one. If connecting with Lakeville's sanitary sewer is not economically feasible in the near future, residents within the Riddles Lake subdivision and along the shoreline of Riddles Lake should consider the use of a wastewater wetland to treat all wastewater from an area rather than relying on individual septic systems. This concept has been used successfully at Lake Maxinkuckee to help reduce the impacts of septic systems on the lake.

6.1.5 Wetland Restoration

Visual observation and historical records indicate at least a portion of the Pleasant and Riddles lakes watershed has been altered to increase its drainage capacity. Hydric soils data indicate that nearly 56% of the watershed's wetland have been converted to other land uses. Riser tiles in low spots on the landscape and tile outlets along the waterways in the Pleasant and Riddles lakes watershed confirm the fact that the landscape has been hydrologically altered.

This hydrological alteration and subsequent loss of wetlands has implications for the watershed's water quality. Wetlands serve a vital role storing water and recharging the groundwater. When wetlands are drained with tiles, the stormwater reaching these wetlands is directed immediately to nearby ditches and streams. This increases the peak flow velocities and volumes in the ditch. The increase in flow velocities and volumes can in turn lead to increased stream bed and bank erosion, ultimately increasing sediment delivery to downstream water bodies. Wetlands also serve as nutrient sinks at times. The loss of wetlands can increase pollutant loads reaching nearby streams and downstream waterbodies.

Restoring wetlands in the Pleasant and Riddles lakes watershed could return many of the functions that were lost when these wetlands were drained. Figure 68 shows the locations where wetland restoration is recommended. While other areas of the watershed could be restored to wetland conditions, the areas shown in Figure 68 were selected because they are areas where large scale restoration is possible. Figures 14 and 15 indicate the potential areas where wetland restorations are possible within the Pleasant and Riddles Lakes watershed.

6.1.6 Conservation Reserve Program

Some landowners in the Pleasant and Riddles Lakes watershed are currently enrolled in the Conservation Reserve Program (CRP), but increased participation in the program would benefit the lake's health. The CRP is a cost-share program designed to encourage landowners to remove a portion of their land from agriculture and establish vegetation on the land in an effort to reduce soil erosion, improve water quality, and enhance wildlife habitat. The CRP targets highly erodible land or land considered to be environmentally sensitive. The CRP provides funding for a wide array of conservation techniques including set-asides, filter strips (herbaceous), riparian buffer strips (woody), grassed waterways, and windbreaks.

Land that is removed from agricultural production and planted with herbaceous or woody vegetation benefits the health of aquatic ecosystems located down gradient of that property in a variety of ways. Woody and/or herbaceous vegetation on CRP land stabilizes the soil on the property, preventing its release off site. Vegetation on CRP land can also filter any runoff reaching it. More importantly, land set aside and planted to prairie or a multi-layer community (i.e. herbaceous, shrub, and tree layers) can help restore a watershed's natural hydrology. Rainwater infiltrates into the soil more readily on land covered with grasses and trees compared to land supporting row crops. This reduces the erosive potential of rain and decreases the volume of runoff. Multi-layer vegetative communities intercept rainwater at different levels, further reducing the erosive potential of rain and volume of runoff.

Given the ecological benefits that land enrolled in CRP provides, it is not surprising that removing land from production and planting it with vegetation has a positive impact on water quality. In a review of Indiana lakes sampled from 1989 to 1993 for the Indiana Clean Lakes Program, Jones (1996) showed that lakes within ecoregions reporting higher percentages of cropland in CRP had lower mean trophic state index (TSI) scores. A lower TSI score is indicative of lower productivity and better water quality.

Specific areas within the watershed that are mapped as highly erodible soil unit and are currently being utilized for agricultural production would benefit the most from the CRP. Some of the fields located throughout the watershed may already utilize grassed waterways under the CRP, but removal of a larger portion of these fields from agricultural production should be considered.

6.1.7 Filter Strips

Specific locations where filter strips could be installed along Heston, Bunch, or Walters ditches and other minor drainages in the watershed would help reduce the pollutant load reaching these waterbodies. Although areas needing filter strips could not be identified during the watershed driving tour, the St. Joseph County SWCD has identified a number of locations where the installation of this practice would improve water quality (Troy Manges, personal communication). Many researchers have verified the effectiveness of filter strips in removing sediment from runoff with reductions ranging from 56-97% (Arora et al., 1996; Mickelson and Baker, 1993; Schmitt et al., 1999; Lee et al, 2000; Lee et al., 2003). Most of the reduction in sediment load occurs within the first 15 feet (4.6 m). Smaller additional amounts are retained and infiltration is increased by increasing the width of the strip (Dillaha et al., 1989). Filter strips have been found to reduce sediment-bound nutrients like total phosphorus but to a lesser extent than they reduce sediment load itself. Phosphorus predominately associates with finer particles like silt and clay that remain suspended longer and are more likely to reach the strip's outfall (Hayes et al., 1984). Filter strips are least effective at reducing dissolved nutrient concentration like those of nitrate, dissolved phosphorus, atrazine, and alachlor, although reductions of dissolved phosphorus, atrazine, and alachlor up to 50% have been documented (Conservation Technology Information Center, 2000). Simpkins et al. (2003) demonstrated 20-93% nitrate-nitrogen removal in multispecies riparian buffers. Short groundwater flow paths, long residence times, and contact with fine-textured sediments favorably increased nitrate-nitrogen removal rates. Additionally, up to 60% of pathogens contained in runoff may be effectively removed. Computer modeling also indicates that over the long run (30 years), filter strips significantly reduce amounts of pollutants entering waterways.

Filter strips are effective in reducing sediment and nutrient runoff from feedlot or pasture areas as well. This is particularly important in the Pleasant and Riddles Lakes watershed where the need for filter strips was associated with livestock pastures. (Specific areas hve not been identified by this study. Please contact the St. Joseph County SWCD for more information if you are interested in installating this practice.) Olem and Flock (1990) report that buffer strips remove nearly 80% of the sediment, 84% of the nitrogen, and approximately 67% of the phosphorus from feedlot runoff. In addition, they found a 67% reduction in runoff volume. The reduction in runoff volume decreases the potential for erosion in any receiving stream. It is important to note that filter strips should be used as a component of an overall waste management system when addressing runoff from pastures and feed lots.

Filter strips are most effective when they: 1. are adequately sized to treat the amount of runoff reaching them (Figure 83); 2. include a diverse variety of species; 3. contain species appropriate for filter strips; and 4. are regularly maintained. Filter strip size depends on the purpose of the strip, but should ideally have at least a 30-foot flow path length (the minimum length across which water flows prior to reaching the adjacent waterbody). The variety of species planted in a filter strip depends upon the desired uses of the strip. For instance, if the filter strip will be grazed or if a landowner wishes to attract a diverse bird community, specific seed mixes should be used in the filter strip. The NRCS or an ecological consultant can help landowners adjust filter strip seed mixes to suit specific needs.

Figure 83. An example of a filter strip with excellent width to maximize the reduction of pollutant loads reaching the adjacent ditch. (Photo taken in Cass County, Indiana.)

During the windshield tour of the Pleasant and Riddles Lakes watershed, filter strips were observed along portions of Heston Ditch and its tributaries. However, the need for filter strips or an increase in the width of existing filter strips was not noted in areas away from the roads. Additional walking tours may be required to identify potential locations not visible from roadways which would benefit from the installation of filter strips. Given the benefits filter strips provide, Pleasant and Riddles Lakes watershed stakeholders should work with the St. Joseph County SWCD to ensure Heston, Bunch, and Walters ditches and other minor tributaries in the watershed are protected with wide, functioning filter strips.

6.1.8 Conservation Tillage

Removing land from agricultural production is not always feasible. Conservation tillage methods should be utilized on highly erodible agricultural land where removing land from production is not an option. Conservation tillage refers to several different tillage methods or systems that leave at least 30% of the soil covered with crop residue after planting (Holdren et al., 2001). Tillage methods encompassed by the phrase "conservation tillage" include no-till, mulch-till, and ridge-till. The crop residue that remains on the landscape helps reduce soil erosion and runoff water volume.

Several researchers have demonstrated the benefits of conservation tillage in reducing pollutant loading to streams and lakes. A comprehensive comparison of tillage systems showed that no-till results in 70% less herbicide runoff, 93% less erosion, and 69% less water runoff volume when compared to conventional tillage (Conservation Technology Information Center, 2000). Reductions in pesticide loading have also been reported (Olem and Flock, 1990). In his review of Indiana lakes, Jones (1996) documented lower mean lake trophic state index scores in ecoregions with higher percentages of conservation tillage. A lower TSI score is indicative of lower productivity and better water quality.

Although an evaluation of the exact percentage of watershed crop land on which producers were utilizing conservation tillage methods was beyond the scope of this study, use of conservation tillage on some of the agricultural land was noted during the windshield tour of the watershed. County-wide estimates from tillage transect data may serve as a reasonable estimate of the amount of crop land on which producers are utilizing conservation tillage methods in the Pleasant and Riddles lakes watershed. County-wide tillage transect data for St. Joseph County provides an estimate for the portion of cropland in conservation tillage for the Pleasant and Riddles lakes watershed. In St. Joseph County, corn producers utilize no-till methods on 8% of corn fields and some form of reduced tillage on 52% of corn fields (IDNR, 2005b). The percentage of corn fields on which no-till methods were used in St. Joseph County was below the statewide median percentage. In total, St. Joseph County ranks 70th in terms of percentage of fields utilizing no-till farming methods for corn production (IDNR, 2005a). St. Joseph County soybean producers used no-till methods on 41% of soybean fields and some form of reduced tillage on 48% of soybean fields in production (IDNR, 2005b). In total, St. Joseph County ranks 76th in terms of percentage of fields utilizing no-till farming methods for corn production (IDNR, 2005a).

6.1.9 Livestock Restriction

Livestock that have unrestricted access to a lake, stream, or wetland have the potential to degrade the waterbody's water quality and biotic integrity. Livestock can deliver nutrients and pathogens directly to a waterbody through defecation. Livestock also degrade stream and lake ecosystems indirectly. Trampling and removal of vegetation through grazing of riparian zones can weaken banks and increase the potential for bank erosion. Trampling can also compact soils in a wetland or riparian zone decreasing the area's ability to infiltrate water runoff. Removal of vegetation in a wetland or riparian zone also limits the area's ability to filter pollutants in runoff. The degradation of a waterbody's water quality and habitat typically results in the impairment of the biota living in the waterbody.

Livestock access to Pleasant Lake and Heston Ditch was a concern noted in two spots in the Pleasant and Riddles Lakes watershed. One area of concern is the pasture located along the eastern shoreline of Pleasant Lake. A horse was observed grazing in the low lying area adjacent to the shoreline. This horse also has direct access to the lake. Excluding the horse from the lake is recommended at this site. The second site is located south of State Road 4 at its intersection with Heston Ditch. Horses appear to have access to the stream at this location. The stream banks also appear to be damaged by grazing and trampling. This area would benefit from exclusion fencing and stabilization of the stream banks.

Restoring areas impacting by livestock grazing often involves several steps. First, the livestock in these areas should be restricted from the wetland or stream to which they currently have access. If necessary an alternate source of water should be created for the livestock. Second, the wetland or riparian zone where the livestock have grazed should be restored. This may include stabilizing or reconstructing the banks using bioengineering techniques. Minimally, it involves installing filter strips along banks or wetland edge and replanting any denuded areas. Finally, if possible, drainage from the land where the livestock are pastured should be directed to flow through a constructed wetland to reduce pollutant loading, particularly nitrate-nitrogen loading, to the adjacent waterbody. Complete restoration of aquatic areas impacted by livestock will help reduce pollutant loading (particularly nitrate-nitrogen, sediment, and pathogens) to Pleasant and Riddles lakes.

6.1.10 Parkland and Campground Management

The management techniques described above for individual residential properties are also applicable to the recreational park located within Lakeville and/or Beaver Ridge Campground located north of State Road 4 and west of Maple Road. Eliminating or reducing fertilizer use, utilizing phosphorus free fertilizer, and preventing organic waste (yard, pet, and wildlife waste) from reaching Heston Ditch, and subsequently Pleasant Lake, are important management steps that should be taken in the Hoosier Park (Figure 84). All of the stormwater from the park flows south and west to a detention basin before reaching Heston Ditch. Reducing the use of fertilizers and pesticides and limiting organic waste from reaching the detention basin will all help reduce sediment and nutrient loading to Heston Ditch from Hoosier Park.

Figure 84. Parkland that could benefit from the use of phosphorus free fertilizer and the installation of stormwater wetland to filter sediment and nutrients prior to them exiting the property.

Beaver Ridge Campground is located adjacent to Heston Ditch near the intersection of Maple Road and State Road 4. The campground hosts up to 800 travel trailers and primitive campers throughout the summer months; up to 400 campers are present at the site year-around (Lawson-Fisher Associates, 2001). The facility includes a pool, shower house, bathrooms, and laundry facilities. All wastewater from the facility flows into holding tanks or a septic system (St. Joseph County Health Department, personal communication) which eventually reach Heston Ditch via groundwater flow. Eliminating or reducing fertilizer use and preventing organic waste (yard, pet, and wildlife waste) from reaching the ditch are important management steps that should be taken in the campground. Utilizing an alternative waste treatment system to treat human wastewater should seriously be considered in these areas. A wastewater wetland is ideal for servicing a campground since, as mentioned above, the wetland is operating at its maximum efficiency during the summer months. This coincides with the peak use of the campgrounds. Installation of wastewater wetlands to service Beaver Ridge Campground may actually reduce the waste stream reaching the leach field, ultimately reducing the pollutant load to the lake.

6.1.11 Future Development Issues

Developable land is located around both Pleasant and Riddles lakes and around the edges of Lakeville. Two areas are already under development on the northeast and northwest corners of Lakeville. Other areas adjacent to the City of Lakeville are currently included in plans for future housing and commercial developments. Many of the same urban BMPs listed above can be applied to future residential and commercial developments; however, other measures may be taken during development phases to protect the ecological health of Pleasant and Riddles lakes. These measures typically fall into one of three categories: limiting imperviousness of the development, 2. focusing on stormwater pollutant source and conveyance reduction, and 3. designing site-specific developments. The following paragraphs described these three categories.

Limit Imperviousness
As areas are developed for residential and commercial use, roads, driveways, sidewalks and parking lots replace forested areas and active or fallow farm fields. While these impervious surfaces provide better "car habitat", they do not provide the same filtration and infiltration of stormwater as the vegetation does. Bannerman et al. (1993) found streets and parking lots to be "critical sources" of stormwater contaminants in their study conducted in Madison, Wisconsin. Impervious surfaces also concentrate stormwater pollutants and increase runoff velocities while conveying the water. This alters the natural hydrology of the watershed and typically increases pollutant loading to receiving waterbodies. Research suggests that the water quality of receiving waterbodies begins to deteriorate once 10% of a waterbody's watershed is covered with impervious surfaces. While setting a goal of less than 10% impervious surface coverage is possible in some of the subwatersheds draining to Pleasant and Riddles lakes, it is impossible in other subwatersheds, such as the Bunch Ditch subwatershed. Nonetheless, efforts should be made to limit the amount of impervious surface to only that absolutely necessary.

Several techniques are available to land planners to reduce the amount of impervious surfaces in new development. For example, planners can employ conservation design in residential areas. These design patterns cluster housing units together leaving more open space to buffer the impacts of the development. Subdivision designs should minimize street length in the housing layout and avoid cul-de-sacs without open centers. Residential street width and parking lot size should be also minimized. Although not always popular, shared driveways reduce pavement in residential areas as well. Porous pavement should be utilized in low traffic areas such as sidewalks and overflow parking areas of commercial developments. These are just of few of the possible alternatives for reducing the amount of impervious surfaces in a watershed.

Stormwater Pollutant Source and Conveyance Reduction
Many of the best management practices utilized in the existing commercial and residential developments, such as detention basins, treat stormwater volume and pollutants at the end of the line. Equal consideration should be given to practices that limit the creation or source of pollutants and practices that treat stormwater in route to an end-of-the-line treatment structure. For example, where site conditions allow, curb and gutter systems should be replaced with grassed shoulders and roadside swales to promote vegetative uptake of pollutants and infiltration of stormwater prior to its release in a detention basin or storm sewer. This would reduce both the amount of pollutants and volume of stormwater that the detention basin needs to treat. Curb and gutter systems do not provide any treatment of stormwater in route to the-end-of-the line structural BMP.

Reduction of pollutants at their source is especially important considering that many of the structural stormwater BMP have limitations on their pollutant removal capacity. Many stormwater BMPs report good pollutant removal efficiencies. For example, wet detention basins can remove close to 80% of the total suspended solid load to the basin. Unfortunately, over time the 20% that passes through may be sufficient to accelerate the degradation of sensitive ecosystems downstream of the BMP. In his examination of stormwater practices, Schueler (1996) identified the "irreducible" concentration of several typical stormwater pollutants discharged from various structural BMPs. For example, evidence from his study suggests that even under the best design and maintenance conditions, the total phosphorus concentration of water discharged from current stormwater BMPs (including stormwater BMP trains) is approximately 0.10 to 0.15 mg/L. These concentrations exceed the 0.03 mg/L threshold for the onset of nuisance algae blooms described in the water quality section of this document. While there is some dilution when the stormwater discharge enters the lake reducing the total phosphorus concentration, over time continual discharge at this rate could accelerate the eutrophication of Pleasant and Riddles lakes.

Source reduction of pollutants includes strong erosion control efforts during construction activities. Sediment release from active construction sites can be several orders of magnitude greater than release from fully developed sites. The potential for release is even greater on highly erodible or potentially highly soils. St. Joseph County and the State of Indiana have erosion control ordinances in place and these ordinances must be enforced. (More information on current development issues is included in the Existing Development section.) Site inspection of the watershed revealed areas where erosion control practices were not effectively implemented. As a consequence, soil left the construction site and entered nearby storm drains. This water eventually reaches the lakes where soil and soil attached pollutants degrade both water quality and habitat. The National Pollutant Discharge Elimination System (NPDES) Phase II regulations will assist local erosion control agencies in strengthening erosion control efforts. Communities can also help by ensuring local erosion control agencies have sufficient funding to hire the staff needed to perform inspections and adequate regulatory power to enforce existing rules.

Site-Specific Design
A corollary to source and conveyance reduction of stormwater pollutants is requiring any new development to consider existing natural features of the property in its site design. For example, should developers build on the open lot along Heston Ditch, buildings should be clustered as far away from the open creek, preserving a buffer zone around the creek. Similarly, residential subdivision development proposed in the areas of the watershed where soils are generally more permeable should utilize grassed shoulders and roadside infiltration swales rather than curb and gutter systems, which are present in some of the newer residential subdivisions around the lakes. Additionally, ordinances should allow flexibility in determining appropriate BMPs on a case-by-case basis. Ordinances should also create incentives for developers to reduce stormwater runoff at its source and to choose BMP options with high removal efficiencies for phosphorus, the primary contaminant of concern in the Pleasant and Riddles lakes watershed.

6.2 In-Lake Management

6.2.1 Aquatic Plant Management
Development of an aquatic plant management plan is also a recommended in-lake management step for Pleasant and Riddles lakes. Like a recreational use management plan, an aquatic plant management plan takes into account the lakes' current and historical ecological condition as well as the recreational desires of the lakes' user groups. The following is a list of recommendations that should form the foundation of any aquatic plant management plan for Pleasant and Riddles lakes. Lake users should remember that rooted plants are a vital part of a healthy functioning lake ecosystem; complete eradication of rooted plants is neither desirable nor feasible. A good aquatic plant management plan will reflect these facts.

1. Due to sparseness of the vegetative community along the developed eastern shoreline of Riddles Lake, aquatic plant management techniques aimed at reducing plant growth are not recommended at this time in this area. The vegetation present likely does not inhibit most

recreational uses of the area. If individual residents feel the amount of plant growth in front of their property is limiting the recreational potential of the lake, these residents might consider management techniques such as hand harvesting of plant material or the use of bottom covers.

Pro-active residents should consider planting emergent species along their shorelines. The eastern shoreline lacks emergent plant coverage. Planting emergent species would help filter pollutants entering the lake via stormwater runoff and provide additional habitat for fish and other water dependent fauna. Emergent vegetation often discourages geese, which in large numbers can impair a lake's water quality, from taking up residence on lakes. Residents should screen all plants for exotic species prior to planting them adjacent to the lakeshore. (See the Management section for additional information on shoreline restoration.)

2. In portions of the lakes adjacent to natural habitat (northern and southern portions of Riddles Lake and the entire shoreline of Pleasant Lake), residents should consider thinning the submerged plant community. Residents should only consider this ***if*** their goal is to increase fishing opportunities on the lakes. In the northern and southern portion of the Riddles Lake and throughout Pleasant, canopy coverage of Eurasian watermilfoil and coontail is quite dense, often accounting for more than 20% of the canopy cover. This creates an abundance of cover for prey fish (e.g. bluegills) to hide from predators. The result in situations like this is an explosion in panfish populations and consequent stunting of these fish due to increased competition for limited resources. One potential aquatic plant management technique that may be applicable in this situation is the use of a harvester to cut cruising lanes for predators (bass). Any use of a harvester in lakes containing Eurasian watermilfoil should be avoided until after the Eurasian watermilfoil is under control. The use of a harvester can cause fragmentation of Eurasian watermilfoil which could result in the spread of this plant to other areas of the lake or to lakes downstream. Any aquatic plant management techniques utilized should include removal of the aquatic plant material from the lake. Dead plant material releases nutrients and utilizes oxygen when it decomposes. In-lake sampling indicates that both Pleasant and Riddles lakes already possess high nutrient levels, and they do not need additional input from plant decay. Furthermore, less than 30% of the lakes' water columns are oxic. Plant decay would reduce oxygen levels even more, limiting fish habitat and increasing the potential for release of phosphorus from the lakes' bottom sediments. Any aquatic plant management efforts undertaken to improve fishing opportunities should include consultation with the IDNR Division of Fish and Wildlife. Division of Fish and Wildlife biologists have managed the region's lakes for decades and would provide the best guidance on steps residents can take to manage the Pleasant and Riddles lakes fishery.

3. Take action to address the Eurasian watermilfoil population in Pleasant Lake and, secondarily, address the Eurasian watermilfoil population in Riddles Lake. Although the amount of Eurasian watermilfoil in Pleasant and Riddles lakes is not high relative to some other lakes in the region, this species has the potential to proliferate and cover a large portion of the lakes. Eurasian watermilfoil offers poor habitat to the lakes' inhabitants and often interferes with recreational uses of the lakes. Spot chemical treatments may be the best management tool at this time to control the spread of the species. Lake users should also educate themselves on the species. Taking precautionary measures such as ensuring that all plant material is removed from their boat propellers following boat use prevents the

spread of the species. Lake users should also refrain from boating through stands of Eurasian watermilfoil. Pieces of the plant as small as one inch in length that are cut by a boat propeller as it moves through a stand of Eurasian watermilfoil can sprout and establish a new plant. Lake users should also take care to inspect trailers, propellers, boats, and other items utilized on the lakes to ensure that they are free of Eurasian watermilfoil fragments to prevent spreading this exotic plant to other area lakes. Signage at the public boat ramp informing visitors of these best management practices would also be useful. IDNR approval is required to post any signs at the public boat ramp.

4. Implement watershed and in-lake management techniques to improve the lakes' water quality. The lakes' poor water quality is likely limiting the establishment of a diverse submerged aquatic plant community. Historical and current surveys of lakes located throughout the region indicate that a much more diverse submerged aquatic plant community is possible. While it is not realistic to expect the return of rarer more sensitive species such as Fries pondweed or minor bladderwort, it is realistic to expect the growth of species as such eel grass, elodea, and floating leaf pondweed. These species are generally tolerant of poor water clarity and commonly found in eutrophic lakes in the area. An improvement in Pleasant and Riddles lakes' water quality and clarity might allow the return of these species, creating a more diverse and healthy aquatic plant community.

A good aquatic plant management plan includes a variety of management techniques applicable to different parts of a lake depending on the lake's water quality, the characteristics of the plant community in different parts of the lakes, and lake users' goals for different parts of the lakes. Many aquatic plant management techniques, including chemical control, harvesting, and biological control, require a permit form the IDNR. Depending on the size and location of the treatment area, even individual residents may need a permit to conduct a treatment. Residents should contact the IDNR Division of Fish and Wildlife before conducting any treatment. The following paragraphs describe some aquatic plant management techniques that may be applicable to Pleasant and Riddles lakes, given its specific ecological condition.

Chemical Control

It is likely that some residents may have conducted their own spot treatments around piers and swimming areas. It is important for residents to remember that any chemical herbicide treatment program should always be developed with the help of a certified applicator who is familiar with the water chemistry of the target lake. In addition, application of a chemical herbicide may require a permit from the IDNR, depending on the size and location of the treatment area. Information on permit requirements is available from the IDNR Division of Fish and Wildlife or conservation officers.

Herbicides vary in their specificity to given plants, method of application, residence time in the water, and the use restrictions for the water during and after treatments. Herbicides (and algaecides; chara is an algae) that are non-specific and require whole lake applications to work are generally not recommended. Such herbicides can kill non-target plants and sometimes even fish species in a lake. Costs of an herbicide treatment vary from lake to lake depending upon the type of plant species present in the lake, the size of the lake, access availability to the lake, the water chemistry of the lake, and other factors. Typically in northern Indiana, costs for treatment range from $300 to $400 per acre or $750 to $1000 per hectare (Cecil Rich, IDNR, personal communication).

While providing a short-term fix to the nuisances caused by aquatic vegetation, chemical control is not a lake restoration technique. Herbicide and algaecide treatments do not address the reasons why there is an aquatic plant problem, and treatments need to be repeated each year to obtain the desired control. In addition, some studies have shown that long-term use of copper sulfate (algaecide) has negatively impacted some lake ecosystems. Such impacts include an increase in sediment toxicity, increased tolerance of some algae species, including some blue-green (nuisance) species, to copper sulfate, increased internal cycling of nutrients, and some negative impacts on fish and other members of the food chain (Hanson and Stefan, 1984 cited in Olem and Flock, 1990).

Chemical treatment should be used with caution on Pleasant and Riddles lakes since treated plants are often left to decay in the water. This will contribute nutrients to the lake's water column. Additionally, plants left to decay in the water column will consume oxygen. The in-lake sampling conducted during this study showed that Pleasant and Riddles lakes possessed relatively high nutrient concentrations compared to many Indiana lakes. As evidenced during the plant survey, the lakes' total phosphorus concentrations are high enough to support filamentous algae and based on the water chemistry samples collected during the in-lake assessment may also experience algal blooms. Spot chemical treatments are recommended only for patches of Eurasian watermilfoil and dense areas of coontail.

Mechanical Harvesting

Harvesting involves the physical removal of vegetation from lakes. Harvesting should also be viewed as a short-term management strategy. Like chemical control, harvesting needs to be repeated yearly and sometimes several times within the same year. (Some carry-over from the previous year has occurred in certain lakes.) Despite this, harvesting is often an attractive management technique because it can provide lake users with immediate access to areas and activities that have been affected by excessive plant growth. Mechanical harvesting is also beneficial in situations where removal of plant biomass will improve a lake's water chemistry. (Chemical control leaves dead plant biomass in the lake to decay and consume valuable oxygen.)

Macrophyte response to harvesting often depends upon the species of plant and particular ways in which the management technique is performed. Pondweeds, which rely on sexual reproduction for propagation, can be managed successfully through harvesting. However, many harvested plants, especially milfoil, can re-root or reproduce vegetatively from the cut pieces left in the water. Plants harvested several times during the growing season, especially late in the season, often grow more slowly the following season (Cooke et al., 1993). Harvesting plants at their roots is usually more effective than harvesting higher up on their stems (Olem and Flock, 1990). This is especially true with Eurasian watermilfoil and curly leaf pondweed. Benefits are also derived if the cut plants and the nutrients they contain are removed from the lake. Harvested vegetation that is cut and left in the lake ultimately decomposes, contributing nutrients and consuming oxygen.

Hand harvesting may be the most economical means of harvesting on Pleasant and Riddles lakes. Hand harvesting is recommended in small areas where human uses are hampered by extensive growths (docks, piers, beaches, boat ramps). In these small areas, plants can be efficiently cut and removed from the lake with hand cutters such as the Aqua Weed Cutter (Figure 85). In less than one hour every 2 to 3 weeks, a homeowner can harvest 'weeds' from along docks and piers. Depending on the model, hand-harvesting equipment for smaller areas cost from $50 to $1500 (McComas, 1993). To reduce the cost, several homeowners can invest together in such a cutter. Alternatively, a lake association may purchase one for its members. This sharing has worked on other Indiana lakes with aquatic plant problems. Use of a hand harvester is more efficient and quick-acting, and less toxic for small areas than spot herbicide treatments. Depending on the size to be treated, a permit may be required for hand-harvesting. (The IDNR Division of Fish & Wildlife can assist lake residents in determining whether a permit is needed and how to obtain one.)

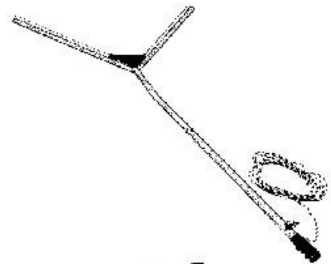

Figure 85. An aquatic weed cutter designed to cut emergent weeds along the edge of ponds. It has a 48" cutting width, uses heavy-duty stainless steel blades, can be sharpened, and comes with an attached 20' rope and blade covers.

Biological Control

Biological control involves the use of one species to control another species. Often when a plant species that is native to another part of the world is introduced to a new country with suitable habitat, it grows rapidly because its native predators have not been introduced to the new country along with the plant species. This is the case with some of the common pest plants in northeast Indiana such as Eurasian watermilfoil and purple loosestrife. Neither of these species is native to Indiana, yet both exist in and around St. Joseph County.

Researchers have studied the ability of various insect species to control both Eurasian watermilfoil and purple loosestrife. Cooke et al. (1993) points to four different species that may reduce Eurasian watermilfoil infestations: *Triaenodes tarda*, a caddisfly, *Cricotopus myriophylii*, a midge, *Acentria nivea*, a moth and *Litodactylus leucogaster*, a weevil. Recent research efforts have focused on the potential for *Euhrychiopsis lecontei*, a native weevil, to control Eurasian watermilfoil. Purple loosestrife biocontrol researchers have examined the potential for three insects, *Gallerucella calmariensis, G. pusilla*, and *Hylobius transversovittatus,* to control the plant.

While the population of purple loosestrife on Riddles Lake is relatively small and therefore may not be suitable for biological control efforts, it may be worthwhile for Riddles Lake residents to understand the common biocontrol mechanisms for this species should the situation on the lake change. Conversely, the Pleasant Lake purple loosestrife population possessed great enough density for the release of *Gallerucella calmariensis* and *G. pusilla* at the IDNR boat ramp in 1996. By 1999, the IDNR estimated that the population of purple loosestrife in northern portion of Pleasant Lake was being controlled by the beetles (IDNR, 2005). Lake users and residents should also be cognizant of infestation issues and biocontrol mechanisms for Eurasian watermilfoil. Therefore, treatment options for the plant are discussed below merely as reference material for use in case of future infestation. Residents and lake users should also be aware that under new regulations an IDNR permit is required for the implementation of a biological control program on a lake.

Eurasian Watermilfoil

Euhrychiopsis lecontei has been implicated in a reduction of Eurasian watermilfoil in several Northeastern and Midwestern lakes (USEPA, 1997). *E. lecontei* weevils reduce milfoil biomass by two means: one, both adult and larval stages of the weevil eat different portions of the plant and two, tunneling by weevil larvae cause the plant to lose buoyancy and collapse, limiting its ability to reach sunlight. The weevils' actions also cut off the flow of carbohydrates to the plant's root crowns impairing the plant's ability to store carbohydrates for over wintering (Madsen, 2000). Techniques for rearing and releasing the weevil in lakes have been developed and under appropriate conditions, use of the weevil has produced good results in reducing Eurasian watermilfoil. A nine-year study of nine southeastern Wisconsin lakes suggested that weevil activity might have contributed to Eurasian watermilfoil declines in the lakes (Helsel et al, 1999).

Cost effectiveness and environmental safety are among the advantages to using the weevil rather than traditional herbicides in controlling Eurasian watermilfoil (Christina Brant, EnviroScience, personal communication). Cost advantages include the weevil's low maintenance and long-term effectiveness versus the annual application of an herbicide. In addition, use of the weevil does not have use restrictions that are required with some chemical herbicides. Use of the weevil has a few drawbacks. The most important one to note is that reductions in Eurasian watermilfoil are seen over the course of several years in contrast to the immediate response seen with traditional herbicides. Therefore, lake residents need to be patient. Additionally, the weevils require natural shorelines for over-wintering.

The Indiana Department of Natural Resources released *E. lecontei* weevils in three Indiana lakes to evaluate the effectiveness of utilizing the weevils to control Eurasian watermilfoil in Indiana lakes. The results of this study were inconclusive (Scribailo and Alix, 2003), and the IDNR considers the use of the weevils on Indiana lakes an unproven technique and only experimental (Rich, 2005). If future infestation of Eurasian watermilfoil should occur, Pleasant and Riddles lakes residents should take the lack of proven usefulness in Indiana lakes into consideration before attempting treatment of the lake's Eurasian watermilfoil with the *E. lecontei* weevils.

Purple Loosestrife

Biological control may also be possible for inhibiting the growth and spread of the emergent purple loosestrife. Like Eurasian watermilfoil, purple loosestrife is an aggressive non-native species. Once purple loosestrife becomes established in an area, the species will readily spread and take over the shallow water and moist soil environment, excluding many of the native species which are more valuable to wildlife. Conventional control methods including mowing, herbicide applications, and prescribed burning have been unsuccessful in controlling purple loosestrife.

Some control has been achieved through the use of several insects. A pilot project in Ontario, Canada reported a decrease of 95% of the purple loosestrife population from the pretreatment population (Cornell Cooperative Extension, 1996). Four different insects were utilized to achieve this control. These insects have been identified as natural predators of purple loosestrife in its native habitat. Two of the insects specialize on the leaves, defoliating a plant (*Gallerucella calmariensis* and *G. pusilla*), one specializes on the flower, while one eats the roots of the plant (*Hylobius transversovittatus*). Insect releases in Indiana to date have had mixed results. After six years, the loosestrife of Fish Lake in LaPorte County is showing signs of deterioration.

Like biological control of Eurasian watermilfoil, use of purple loosestrife predators offers a cost-effective means for achieving long-term control of the plant. Complete eradication of the plant cannot be achieved through use of a biological control. Insect (predator) populations will follow the plant (prey) populations. As the population of the plant decreases, so will the population of the insect since their food source is decreasing.

Bottom Covers

Bottom shading by covering bottom sediments with fiberglass or plastic sheeting materials provides a physical barrier to macrophyte growth. Buoyancy and permeability are key characteristics of the various sheeting materials. Buoyant materials (polyethylene and polypropylene) are generally more difficult to apply and must be weighted down. Unfortunately, sand or gravel anchors used to hold buoyant materials in place can act as substrate for new macrophyte growth. Any bottom cover materials placed on the lake bottom must be permeable to allow gases to escape from the sediments; gas escape holes must be cut in impermeable liners. Commercially available sheets made of fiberglass-coated screen, coated polypropylene, and synthetic rubber are non-buoyant and allow gases to escape, but cost more (up to $66,000 per acre or $163,000 per hectare for materials, Cooke and Kennedy, 1989). Indiana regulations specifically prohibit the use of bottom covering material as a base for beaches.

Due to the prohibitive cost of the sheeting materials, sediment covering is recommended for only small portions of lakes, such as around docks, beaches, or boat mooring areas. This technique may be ineffective in areas of high sedimentation, since sediment accumulated on the sheeting material provides a substrate for macrophyte growth. The IDNR requires a permit for any permanent structure on the lake bottom, including anchored sheeting.

Preventive Measures

Preventive measures are necessary to curb the spread of nuisance aquatic vegetation. Although milfoil is thought to 'hitchhike' on the feet and feathers of waterfowl as they move from infected to uninfected waters, the greatest threat of spreading this invasive plant is humans. Plant fragments snag on boat motors and trailers as boats are hauled out of lakes (Figure 86). Milfoil, for example, can survive for up to a week in this state; it can then infect a milfoil-free lake when the boat and trailer are launched next. It is important to educate boaters to clean their boats and trailers of all plant fragments each time they retrieve them from a lake.

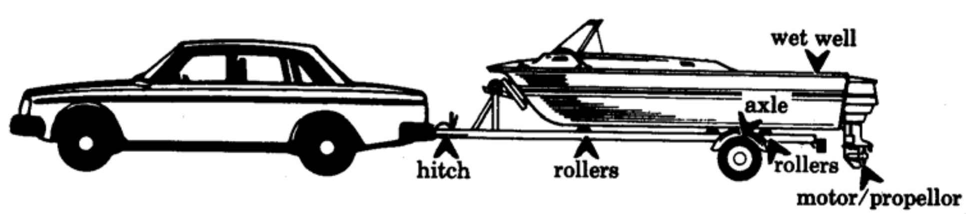

Figure 86. Locations where aquatic macrophytes are often found on boats and trailers.

Educational programs are effective ways to manage and prevent the spread of aquatic nuisance species (ANS) such as Eurasian watermilfoil, zebra mussels, and others. Of particular help are signs at boat launch ramps asking boaters to check their boats and trailers both before launching and after retrieval. All plants should be removed and disposed of in refuse containers where they cannot make their way back into the lake. The Illinois-Indiana Sea Grant Program has examples of boat ramp signs and other educational materials that can be used at Pleasant and Riddles lakes. Although

Eurasian watermilfoil already exists in Pleasant and Riddles lakes, educational programs and lake signage will help prevent the spread of this nuisance species to other lakes. This is particularly important given the popularity of Pleasant and Riddles lakes. Non-resident anglers and other visitors will use their boats in other lakes in addition to Pleasant and Riddles lakes, potentially spreading Eurasian watermilfoil to uninfested lakes. Signs addressing any best management practices to prevent the spread of nuisance aquatic species will ultimately help protect all lakes as new nuisance (often non-native) species are finding their way to Indiana lakes all the time.

6.2.2 Dredging

Sediment removal by dredging removes phosphorus enriched sediments from lake bottoms, thereby reducing the likelihood of phosphorus release from the sediments. Dredging also deepens lakes for recreational purposes and limits the growth area for rooted macrophytes. Because this technique is capital-intensive, it can only be justified in small lakes or in lakes where the sediment-bound phosphorus is limited to a small, identifiable area. Dredging is not effective in lakes where additional sediment loading cannot be controlled. Sediment removal might be justified in a seepage lake, where watershed controls are not applicable.

A potentially troublesome consequence of dredging is the resuspension of sediments during the dredging operation and the possible release of toxic substances bound loosely to sediments. Because of this, sediment cores must be analyzed prior to dredging to determine sediment composition. Such an analysis would also provide a profile of phosphorus concentrations with depth in the sediments. If phosphorus concentrations do not decline with depth, dredging for phosphorus control would not be effective since phosphorus could continue to be released from the sediments.

Cost must be carefully evaluated before dredging operations occur. In deep lakes, the cost of dredging can be prohibitive. In small lakes, it may be easier and more cost-effective to dewater the lake and remove sediments with front end loaders and trucks. Perhaps the most economically and logistically prohibitive part of a dredging operation is disposal of the removed sediments. Sediment disposal must be investigated *before* the decision to dredge can be made. Dredging costs range from $25,000 to $30,000 per acre (JFNew, 2005a; JFNew, 2005c). This estimate excludes any administrative costs associated with dredging. Any dredging activities in a freshwater public lake will require permits from the Corps of Engineers, the Indiana Department of Environmental Management, and Indiana Department of Natural Resources, further increasing the cost of dredging.

Dredging should not be the first priority to resolve sediment and nutrient problems in Pleasant and Riddles lakes. However, the Lakeville Business Owners Association, Riddles Lake Conservation Club, and area residents prioritized dredging as one of the first items that they wished to accomplish. A sediment removal plan for the outlets of Bunch and Heston ditches in Pleasant Lake and Heston Ditch in Riddles Lake is being developed concurrent with this diagnostic study. Suggested sediment removal depths and quantities, dredging locations, material disposal site, and cost estimates are documented in the Pleasant and Riddles Lakes Sediment Removal Plan (2005 draft).

6.2.3 Water Quality Monitoring

The Indiana Clean Lakes Volunteer Monitoring Program trains and equips citizen volunteers to measure Secchi disk transparency, water color, total phosphorus, and chlorophyll *a* in Indiana lakes. Citizen volunteers monitor over 115 lakes for transparency and 40 lakes for phosphorus and chlorophyll. Volunteers also have access to temperature and oxygen meters to track changes in these parameters throughout the year. Data collected by volunteers helps elucidate any trends in water quality and provides more timely information with which lake management decisions can be made. Pleasant and Riddles lakes have not participated in this program in the past; however, volunteers have been identified and trained to begin monitoring. Their participation in the Indiana Clean Lakes Volunteer Monitoring Program is highly recommended.

7.0 RECOMMENDATIONS

As noted in the previous section, Pleasant and Riddles lakes currently possess poor water quality. The biotic communities (algae, plants, fish) exhibit characteristics typically observed within lakes which possess high nutrient concentrations like present in Pleasant and Riddles lakes. It is unlikely that the lakes can continue to absorb the pollutant loads they are currently receiving. Results from the modeling and lake and stream assessments indicate that current pollutant concentrations and loads, particularly phosphorus, nitrate, organic matter, and bacteria, are of concern for the lakes' long-term health. Lake residents have already noted declines in water clarity following storm events, suggesting sediment is also of concern.

Given the Pleasant and Riddles lakes' specific characteristics, both in-lake and watershed management is recommended to improve the lakes' water quality. Pleasant and Riddles lakes' high watershed area to lake area ratios suggests actions taken within the watershed will have a significant impact of the lakes' health. Thus, management of watershed issues and near shore drainages and individual residential properties should be prioritized. The lakes' relatively short hydraulic residence time means in-lake management, which can affect nutrient cycling, should receive lower priority.

The following list summarizes the recommendations for improving Pleasant and Riddles lakes' chemical, biological, and physical conditions. The recommendations are separated in two groups based on priority described above. Recommendations in the first group are of higher priority than recommendations in the second group since implementation of these recommendations would provide greatest benefit to Pleasant and Riddles lakes. Implementation of recommendations in the second group is, however, important and should not be ignored. Each of the following recommendations should be implemented and will help improve Pleasant and Riddles lake water quality.

The list is prioritized based on the current ecological conditions of Pleasant and Riddles lakes and their watershed. These conditions may change as land and lake use change requiring a change in the order of prioritization. Watershed stakeholders may also wish to prioritize these management recommendations differently to accommodate specific needs or desired uses of the lakes. It is important for watershed stakeholders to know that actions need not be taken in this order. Some of the smaller, less expensive recommendations, such as the individual property owner recommendations, may be implemented while funds are being raised to implement some of the larger projects. (Appendix N provides a list of possible funding sources to implement recommended projects.) Many of the larger projects will require feasibility studies to ensure landowner willingness to participate in the project and regulatory approval of the project.

Primary Recommendations

1. Work with the Town of Lakeville to correct wastewater treatment plant issues. The Town of Lakeville wastewater treatment plant experienced an overflow in March and July 2005 resulting in excessive loading of nutrients and pathogens to Bunch Ditch, and subsequently, Pleasant and Riddles lakes. Correcting wastewater issues requires an assessment of current and future development pressures and creation of a wastewater management plan. Any plans should, at a minimum, address the following: lift station operation, overflow issues, manual and automatic shut off of pumps, leaking or insufficiently sized pipes, and areas of stormwater infiltration.

2. Work with the owners of the existing residential developments located on the northeast and northwest corners of the Town of Lakeville to correct erosion issues. Both developments require silt fence installation at a minimum. At the time of the watershed tour, it appeared erosion control plans were not being implemented on either property. The St. Joseph County Soil and Water Conservation District is charged with approving, the landowner is charged with implementing, and the IDEM is responsible for enforcing these plans. To correct erosion control issues, it will likely be necessary to work with the St. Joseph County SWCD, the landowner, and the IDEM to correct these issues and implement erosion control practices on these properties.

3. Implement stormwater management techniques throughout the Town of Lakeville including creation of a wetland filter at the southeast corner of Lake Trail and Linden Road.

4. Implement individual property owner management techniques. These apply to all watershed property owners rather than simply those who live immediately adjacent to Pleasant and Riddles lakes.
   a. Reduce the frequency and amount of fertilizer and herbicide/pesticide used for lawn care.
   b. Use only phosphorus-free fertilizer. (This means that the middle number on the fertilizer package listing the nutrient ratio, nitrogen:phosphorus:potassium is 0.)
   c. Consider re-landscaping lawn edges, particularly those along the watershed's lakes and streams, to include low profile prairie species that are capable of filtering runoff water better than turf grass. This is especially important on properties adjacent to Pleasant and Riddles lakes where exotic, invasive species are currently used as landscaping materials.
   d. Consider planting native emergent vegetation along shorelines or in front of existing seawalls to provide fish and invertebrate habitat and dampen wave energy.
   e. Keep organic debris like lawn clippings, leaves, and animal waste out of the water.
   f. Properly maintain septic systems. Systems should be pumped regularly and leach fields should be properly cared for.
   g. Examine all drains that lead from roads, driveways, or rooftops to the watershed's lake and/or streams; consider alternate routes for these drains that would filter pollutants before they reach the water. Stabilize bare drainage ditches with vegetation where possible or rock where flow rates are too high for vegetation.
   h. These lakes are no-wake lakes; boaters should obey the no-wake rules.
   i. Clean boat propellers after lake use and refrain from dumping bait buckets into the lake to prevent the spread of exotic species.

5. Restore wetland habitat within the Pleasant and Riddles lakes watershed where feasible. Figure 68 shows areas that are good candidates for wetland restoration.

6. Minimize the impact of exotic species on the lakes. Eurasian watermilfoil, curly leaf pondweed, purple loosestrife, and reed canary grass were present during the current assessment of the lake. Special care should be taken to prevent the spread of these species and protect the diverse, native submerged rooted plant community. Work in this area should be accomplished in such a manner as to not disturb the purple loosestrife beetle community previously introduced at Pleasant Lake's boat ramp.

7. Post informational signage at the boat launches on Pleasant and Riddles lakes to inform lake users of best management practices to prevent the spread of aquatic nuisance species, particularly Eurasian watermilfoil, curly-leaf pondweed, and zebra mussels. Any signage posted at a public boat launch (Pleasant Lake) requires permission from the IDNR Division of Fish and Wildlife. Because Riddles Lake's boat ramp is privately owned, permission from the IDNR is not required for any signage posted at the ramp.

8. Monitor and improve erosion control techniques on residential development sites and along the Lakeville Conservation Club channel. Bring areas of concern to appropriate authorities.

9. Become an active volunteer in the Indiana Clean Lakes Program volunteer monitoring program. Volunteers have been trained on Pleasant and Riddles lakes but have not yet actively established a monitoring program. Volunteer monitoring is easy and does not take much time. The CLP staff provides the training and equipment needed to participate in the program. The data collected by the volunteer monitor will be extremely useful in tracking long-term trends in the lake water quality and measuring the success of any restoration measures implemented in the watershed.

Secondary Recommendations

10. Work with the St. Joseph County Health Department to determine the cause of the extremely high *E. coli* concentrations observed in Walters Ditch. Potential sources of the bacteria include a failing septic system, wildlife, and livestock.

11. Increase usage of the Conservation Reserve Program in the Pleasant and Riddles Lakes watershed particularly on land mapped in highly erodible soils.

12. Fence livestock out of the Pleasant and Riddles lakes watershed water bodies.

13. Once watershed issues have been addressed, complete sediment removal work as defined in the sediment removal plan. This will address accumulated sediment at the mouths of Heston and Bunch ditches in Pleasant Lake and Heston Ditch in Riddles Lake. Dredging of these areas will likely extend over a number of years and could involve the creation of sediment traps at the mouths of each of the outlets. These actions should only be considered after all options for implementing watershed techniques have been addressed.

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APPENDICES

PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY

ST. JOSEPH COUNTY, INDIANA

APPENDIX A:

GEOGRAPHIC INFORMATION SYSTEMS (GIS) MAP DATA SOURCES

PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY

ST. JOSEPH COUNTY, INDIANA

Appendix A. Geographic Information Systems (GIS) map data sources.

Figure 2. Pleasant and Riddles lakes watershed
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set.

Figure 3. Topographical map of the Pleasant and Riddles Lakes watershed
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Relief coverage is the U.S. Geological Survey National Elevation Data set.

Figure 4. Riddles Lake subwatersheds
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Watershed and subwatershed boundaries were delineated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI.

Figure 5. Pleasant Lake subwatersheds
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Watershed and subwatershed boundaries were delineated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI.

Figure 8. Soil associations in the Pleasant and Riddles Lakes watershed
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Soil associationss coverage is from Reusch, 1990.

Figure 9. Highly erodible and potentially highly erodible soils within the Pleasant and Riddles Lakes watershed.
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Soils coverage is from the Natural Resources Conservation Service National Ssurgo Soils Database. Highly erodible and potentially soils criteria were set by the NRCS.

Figure 10.Soil septic tank suitability within the Pleasant and Riddles Lakes watershed
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Soils coverage is from the Natural Resources Conservation Service National Ssurgo Soils Database. Soil septic tank limitations were set by the NRCS and are reported in Smallwood (1980).

Figure 11. Soil series bordering Pleasant and Fites Lakes
Aerial photographs are from the Indiana University NAIP File system and are available on-line from their website: http://www.indiana.edu/~gisdata/naipdl/map/m10000.html Soils coverage is from the Natural Resources Conservation Service National Ssurgo Soils Database. Soil septic tank limitations were set by the NRCS and are reported in Smallwood (1980).

Figure 12. Soil series bordering Riddles Lake
Aerial photographs are from the Indiana University NAIP File system and are available on-line from their website: http://www.indiana.edu/~gisdata/naipdl/map/m10000.html Soils coverage is from the Natural Resources Conservation Service National Ssurgo Soils Database. Soil septic tank limitations were set by the NRCS and are reported in Smallwood (1980).

Figure 13. Land use in the Pleasant and Riddles Lakes watershed
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Land use comes from the USGS Indiana Land Cover Data Set. The data set was corrected based on 2003 aerial photographs.

Figure 14. Wetlands in the Pleasant and Riddles Lakes watershed
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Wetland location source is U.S. Fish and Wildlife Service National Wetland Inventory GIS coverage.

Figure 15. Hydric soils in the Pleasant and Riddles Lakes watershed
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Soils coverage is from the Natural Resources Conservation Service National Surgo Soils Database. Hydric soil classifications were previously set by the NRCS.

Figure 16. Stream sampling locations
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Sample locations were recorded using a Trimble Pro XRS GPS unit with sub-meter accuracy.

Figure 37. Aerial photograph of Riddles Lakes
Aerial photographs are from the Indiana University NAIP File system and are available on-line from their website: http://www.indiana.edu/~gisdata/naipdl/map/m10000.html

Figure 41. Aerial photograph of Pleasant and Fites lakes
Aerial photographs are from the Indiana University NAIP File system and are available on-line from their website: http://www.indiana.edu/~gisdata/naipdl/map/m10000.html

Figure 51. Pleasant and Riddles lakes plant beds as surveyed July 27, 2005
Shoreline boundaries are from the U.S. Census Bureau TIGER data set. Plant bed coverages are based on field surveys conducted July 28, 2005 and were drawn by JFNew.

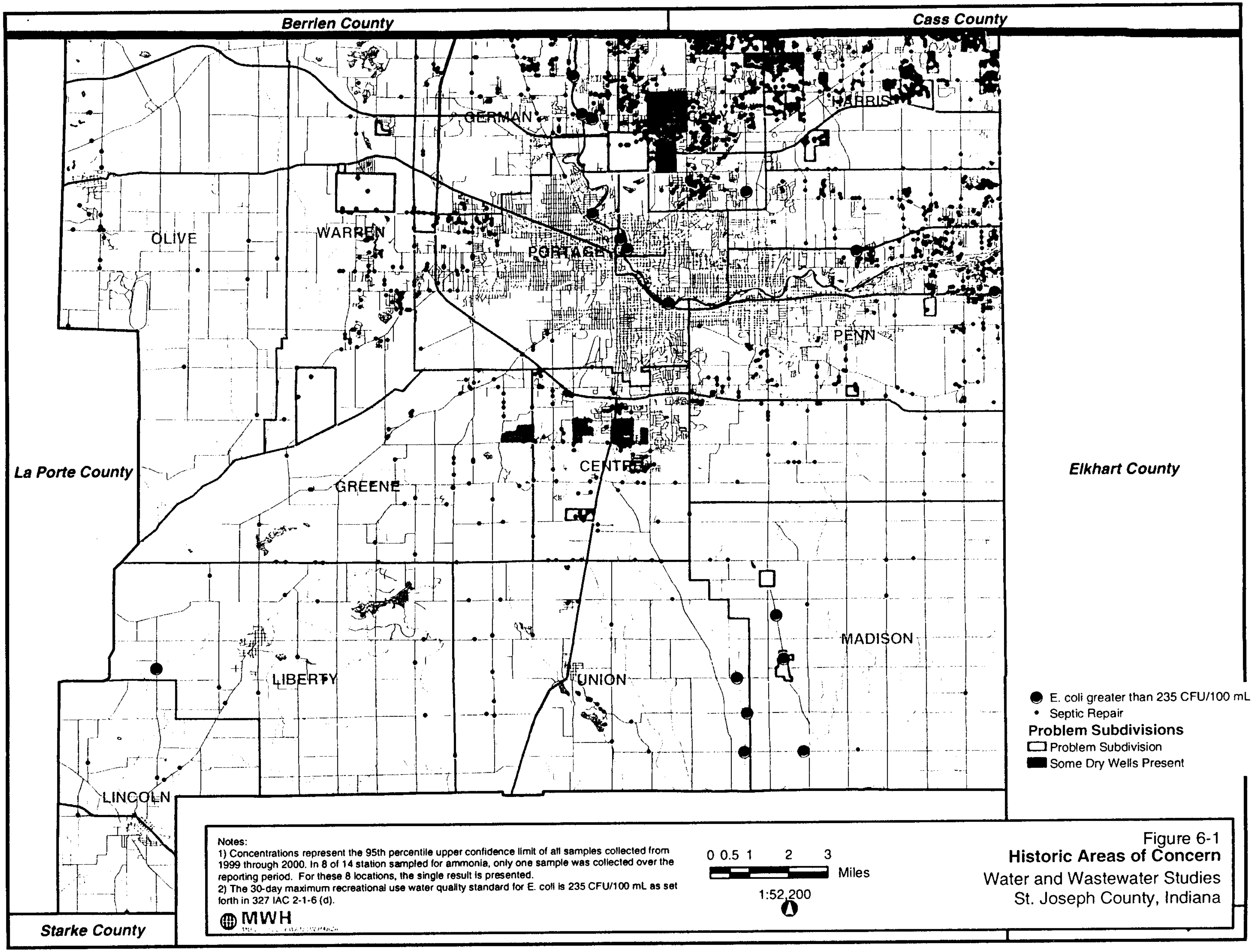
Figure 65. Areas that would benefit from watershed management technique installation
Watershed boundaries generated using ArcView 3.3 Spatial Analyst with a hydrological modeling extension available from ESRI. Computer generated boundaries were field checked for accuracy. Road and stream coverages are from the U.S. Census Bureau TIGER data set. Improvement project locations are based upon field surveys conducted by JFNew. Coverages were drawn by JFNew. Latitude and longitude coordinates for potential water quality improvement projects are listed below.

APPENDIX B:

SEPTIC SYSTEM FAILURES

PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY

ST. JOSEPH COUNTY, INDIANA



Notes:
1) Concentrations represent the 95th percentile upper confidence limit of all samples collected from 1999 through 2000. In 8 of 14 station sampled for ammonia, only one sample was collected over the reporting period. For these 8 locations, the single result is presented.
2) The 30-day maximum recreational use water quality standard for E. coli is 235 CFU/100 mL as set forth in 327 IAC 2-1-6 (d).

MWH

Figure 6-1
Historic Areas of Concern
Water and Wastewater Studies
St. Joseph County, Indiana

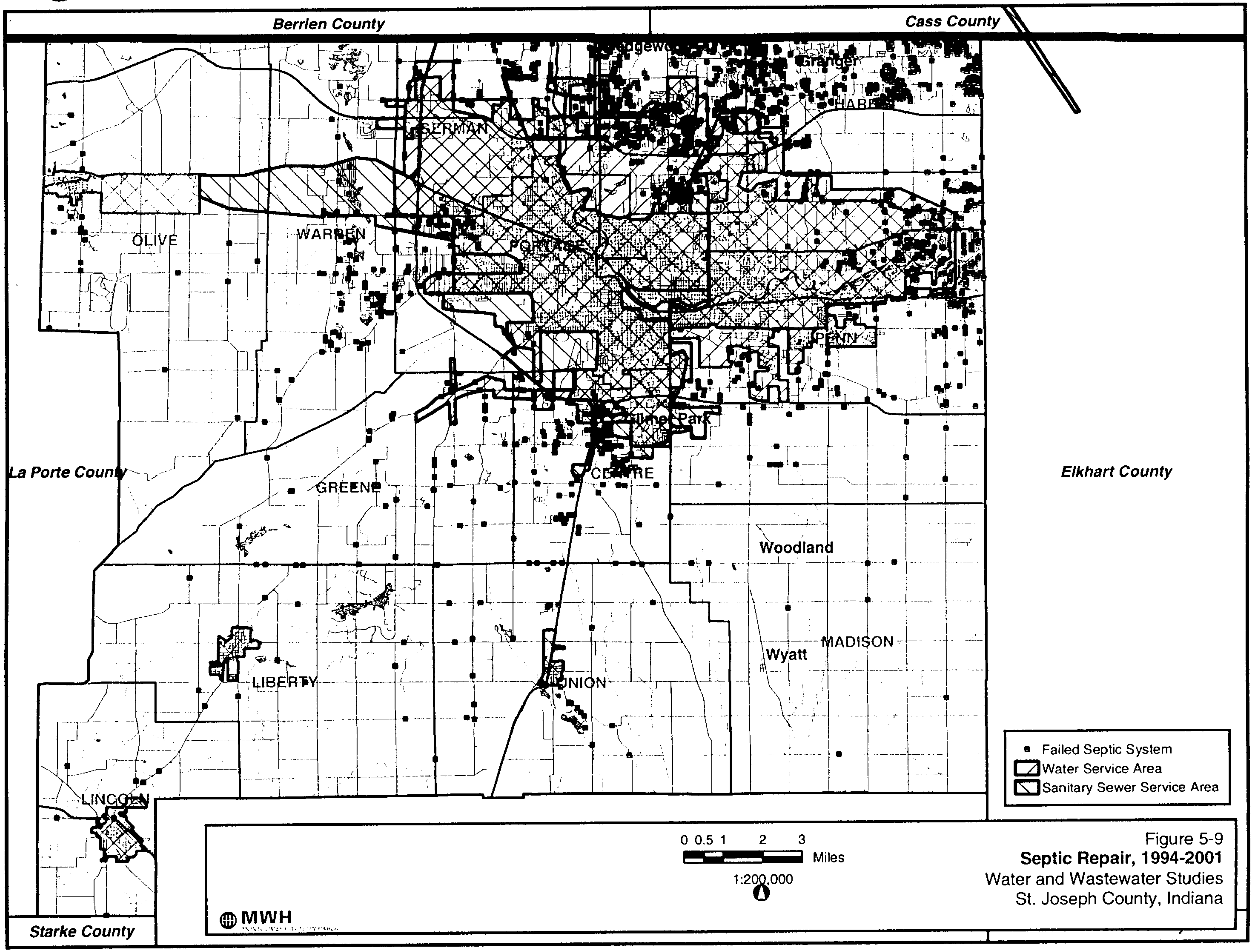


Figure 5-9
Septic Repair, 1994-2001
Water and Wastewater Studies
St. Joseph County, Indiana

APPENDIX C:

ENDANGERED, THREATENED, AND RARE SPECIES LIST, PLEASANT AND RIDDLES LAKES WATERSHED

PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY

ST. JOSEPH COUNTY, INDIANA

ENDANGERED, THREATENED AND RARE SPECIES,
HIGH QUALITY NATURAL COMMUNITIES, AND SIGNIFICANT NATURAL AREAS DOCUMENTED
FROM THE RIDDLES LAKE WATERSHED, ST. JOSEPH COUNTY, INDIANA

TYPE	SPECIES NAME	COMMON NAME	STATE	FED	LOCATION	DATE	COMMENTS
LAKEVILLE							
Mollusk	LYMNAEA STAGNALIS	SWAMP LYMNAEA	SSC	**	T36NR02E 29 NWQ NEQ NWQ	1988	
Reptile	CLONOPHIS KIRTLANDII	KIRTLAND'S SNAKE	SE	**	T36NR02E 33 SWQ SEQ SEQ	1987	
Reptile	EMYDOIDEA BLANDINGII	BLANDING'S TURTLE	SE	**	T36NR02E 22	1999	
Vascular Plant	DIERVILLA LONICERA	NORTHERN BUSH-HONEYSUCKLE	SR	**	T35NR02E 01	1939	

STATE: SX=extirpated, SE=endangered, ST=threatened, SR=rare, SSC=special concern, WL=watch list, SG=significant,** no status but rarity warrants concern

FEDERAL: LE=endangered, LT=threatened, LELT=different listings for specific ranges of species, PE=proposed endangered, PT=proposed threatened, ESA=appearance similar to LE species,**=not listed

APPENDIX D:

ENDANGERED, THREATENED, AND RARE SPECIES LIST, ST. JOSEPH COUNTY, INDIANA

PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY

ST. JOSEPH COUNTY, INDIANA

November 16, 1999

ENDANGERED, THREATENED AND RARE SPECIES DOCUMENTED FROM ST. JOSEPH COUNTY, INDIANA

SPECIES NAME	COMMON NAME	STATE	FED	SRANK	GRANK
VASCULAR PLANT					
ACTAEA RUBRA	RED BANEBERRY	SR	**	S2	G5
ARABIS DRUMMONDII	DRUMMOND ROCKCRESS	SE	**	S1	G5
ARABIS GLABRA	TOWER-MUSTARD	ST	**	S2	G5
ARABIS MISSOURIENSIS VAR DEAMII	MISSOURI ROCKCRESS	SE	**	S1	G4?QT3?Q
ARENARIA STRICTA	MICHAUX'S STITCHWORT	SR	**	S2	G5
ARMORACIA AQUATICA	LAKE CRESS	SE	**	S1	G4?
BOTRYCHIUM MATRICARIIFOLIUM	CHAMOMILE GRAPE-FERN	ST	**	S2	G5
CAREX ALOPECOIDEA	FOXTAIL SEDGE	SE	**	S1	G5
CAREX ATHERODES	AWNED SEDGE	SE	**	S1	G5
CAREX ATLANTICA SSP ATLANTICA	ATLANTIC SEDGE	ST	**	S2	G5T4
CAREX BEBBII	BEBB'S SEDGE	ST	**	S2	G5
CAREX CRAWEI	CRAWE SEDGE	ST	**	S2	G5
CAREX DEBILIS VAR RUDGEI	WHITE-EDGE SEDGE	ST	**	S2	G5T5
CAREX FLAVA	YELLOW SEDGE	ST	**	S2	G5
CAREX PEDUNCULATA	LONGSTALK SEDGE	SR	**	S2	G5
CAREX RETRORSA	RETRORSE SEDGE	SE	**	S1	G5
CAREX SCABRATA	ROUGH SEDGE	SE	**	S1	G5
CAREX SEORSA	WEAK STELLATE SEDGE	SR	**	S2	G4
CAREX STRAMINEA	STRAW SEDGE	ST	**	S2	G5
CHRYSOSPLENIUM AMERICANUM	AMERICAN GOLDEN-SAXIFRAGE	ST	**	S2	G5
CIRSIUM HILLII	HILL'S THISTLE	SE	**	S1	G3
CYPRIPEDIUM CANDIDUM	SMALL WHITE LADY'S-SLIPPER	SR	**	S2	G4
DESCHAMPSIA CESPITOSA	TUFTED HAIRGRASS	SR	**	S2	G5
DIERVILLA LONICERA	NORTHERN BUSH-HONEYSUCKLE	SR	**	S2	G5
DROSERA INTERMEDIA	SPOON-LEAVED SUNDEW	SR	**	S2	G5
ELEOCHARIS MELANOCARPA	BLACK-FRUITED SPIKE-RUSH	ST	**	S2	G4
ELEOCHARIS ROBBINSII	ROBBINS SPIKERUSH	SR	**	S2	G4G5
ERIOCAULON AQUATICUM	PIPEWORT	SE	**	S1	G5
ERIOPHORUM ANGUSTIFOLIUM	NARROW-LEAVED COTTON-GRASS	SR	**	S2	G5
FUIRENA PUMILA	DWARF UMBRELLA-SEDGE	ST	**	S2	G4
GERANIUM ROBERTIANUM	HERB-ROBERT	ST	**	S2	G5
GNAPHALIUM MACOUNII	WINGED CUDWEED	SX	**	SX	G5
JUGLANS CINEREA	BUTTERNUT	WL	**	S3	G3G4
JUNCUS MILITARIS	BAYONET RUSH	SE	**	S1	G4
JUNCUS PELOCARPUS	BROWN-FRUITED RUSH	ST	**	S2	G5
LATHYRUS MARITIMUS VAR GLABER	BEACH PEAVINE	SE	**	S1	G5T4T5
LATHYRUS VENOSUS	SMOOTH VEINY PEA	ST	**	S2	G5
LINUM SULCATUM	GROOVED YELLOW FLAX	SR	**	S2	G5
LUDWIGIA SPHAEROCARPA	GLOBE-FRUITED FALSE-LOOSESTRIFE	SE	**	S1	G5
LYCOPODIUM HICKEYI	HICKEY'S CLUBMOSS	SR	**	S2	G5
LYCOPODIUM OBSCURUM	TREE CLUBMOSS	SR	**	S2	G5
MATTEUCCIA STRUTHIOPTERIS	OSTRICH FERN	SR	**	S2	G5

STATE: SX=extirpated, SE=endangered, ST=threatened, SR=rare, SSC=special concern, WL=watch list, SG=significant,** no status but rarity warrants concern
FEDERAL: LE=endangered, LT=threatened, LELT=different listings for specific ranges of species, PE=proposed endangered, PT=proposed threatened, E/SA=appearance similar to LE species, **=not listed

ENDANGERED, THREATENED AND RARE SPECIES DOCUMENTED FROM ST. JOSEPH COUNTY, INDIANA

SPECIES NAME	COMMON NAME	STATE	FED	SRANK	GRANK
ORYZOPSIS RACEMOSA	BLACK-FRUIT MOUNTAIN-RICEGRASS	ST	**	S2	G5
PANICUM COLUMBIANUM	HEMLOCK PANIC-GRASS	SR	**	S2	G5
PANICUM COMMONSIANUM VAR ADDISONII	COMMONS' PANIC-GRASS	SR	**	S2	G5T5
PANICUM VERRUCOSUM	WARTY PANIC-GRASS	ST	**	S2	G4
PINUS STROBUS	EASTERN WHITE PINE	SR	**	S2	G5
PLATANTHERA DILATATA	LEAFY WHITE ORCHIS	SE	**	S1	G5
PLATANTHERA LEUCOPHAEA	PRAIRIE WHITE-FRINGED ORCHID	SE	LT	S1	G2
POA ALSODES	GROVE MEADOW GRASS	SR	**	S2	G4G5
POA PALUDIGENA	BOG BLUEGRASS	WL	**	S3	G3
POLYGONUM HYDROPIPEROIDES VAR OPELOUSANUM	NORTHEASTERN SMARTWEED	ST	**	S2	G5
POLYGONUM HYDROPIPEROIDES VAR SETACEUM	SWAMP SMARTWEED	SE	**	S1	G5
POPULUS BALSAMIFERA	BALSAM POPLAR	SX	**	SX	G5
PSILOCARYA SCIRPOIDES	LONG-BEAKED BALDRUSH	ST	**	S2	G4
PYROLA VIRENS	GREENISH-FLOWERED WINTERGREEN	SX	**	SX	G5
RHYNCHOSPORA MACROSTACHYA	TALL BEAKED-RUSH	SR	**	S2	G4
RUBUS ENSLENII	SOUTHERN DEWBERRY	SE	**	S1	G4G5Q
RUBUS SETOSUS	SMALL BRISTLEBERRY	SE	**	S1	G5
SALIX SERISSIMA	AUTUMN WILLOW	ST	**	S2	G4
SCHEUCHZERIA PALUSTRIS SSP AMERICANA	AMERICAN SCHEUCHZERIA	SE	**	S1	G5T5
SCIRPUS SMITHII	SMITH'S BULRUSH	SE	**	S1	G5?
SCIRPUS SUBTERMINALIS	WATER BULRUSH	SR	**	S2	G4G5
SELAGINELLA APODA	MEADOW SPIKE-MOSS	SE	**	S1	G5
SILENE REGIA	ROYAL CATCHFLY	ST	**	S2	G3
SORBUS DECORA	NORTHERN MOUNTAIN-ASH	SX	**	SX	G4G5
SPARGANIUM ANDROCLADUM	BRANCHING BUR-REED	ST	**	S2	G4G5
STIPA AVENACEA	BLACKSEED NEEDLEGRASS	ST	**	S2	G5
STROPHOSTYLES LEIOSPERMA	SLICK-SEED WILD-BEAN	ST	**	S2	G5
TOFIELDIA GLUTINOSA	FALSE ASPHODEL	SR	**	S2	G5
TRIGLOCHIN PALUSTRE	MARSH ARROW-GRASS	ST	**	S2	G5
UTRICULARIA CORNUTA	HORNED BLADDERWORT	ST	**	S2	G5
UTRICULARIA PURPUREA	PURPLE BLADDERWORT	SR	**	S2	G5
VACCINIUM OXYCOCCOS	SMALL CRANBERRY	ST	**	S2	G5
VALERIANA ULIGINOSA	MARSH VALERIAN	SE	**	S1	G4Q
VALERIANELLA CHENOPODIIFOLIA	GOOSE-FOOT CORN-SALAD	SE	**	S1	G5
VIBURNUM CASSINOIDES	NORTHERN WILD-RAISIN	SE	**	S1	G5
VIOLA PRIMULIFOLIA	PRIMROSE-LEAF VIOLET	SR	**	S2	G5
XYRIS DIFFORMIS	CAROLINA YELLOW-EYED GRASS	ST	**	S2	G5
MOLLUSCA: GASTROPODA					
CAMPELOMA DECISUM	POINTED CAMPELOMA	SSC	**	S2	G5
LYMNAEA STAGNALIS	SWAMP LYMNAEA	SSC	**	S2	G5

STATE: SX=extirpated, SE=endangered, ST=threatened, SR=rare, SSC=special concern, WL=watch list, SG=significant,** no status but rarity warrants concern

FEDERAL: LE=endangered, LT=threatened, LELT=different listings for specific ranges of species, PE=proposed endangered, PT=proposed threatened, E/SA=appearance similar to LE species, **=not listed

November 16, 1999

ENDANGERED, THREATENED AND RARE SPECIES DOCUMENTED FROM ST. JOSEPH COUNTY, INDIANA

SPECIES NAME	COMMON NAME	STATE	FED	SRANK	GRANK
ARTHROPODA: INSECTA: ODONATA (DRAGONFLIES; DAMSELFLIES)					
SYMPETRUM SEMICINCTUM	BAND-WINGED MEADOWFLY	**	**	S2S3	G5
AMPHIBIANS					
AMBYSTOMA LATERALE	BLUE-SPOTTED SALAMANDER	SSC	**	S2	G5
RANA PIPIENS	NORTHERN LEOPARD FROG	SSC	**	S2	G5
REPTILES					
CLEMMYS GUTTATA	SPOTTED TURTLE	SE	**	S2	G5
CLONOPHIS KIRTLANDII	KIRTLAND'S SNAKE	SE	**	S2	G2
EMYDOIDEA BLANDINGII	BLANDING'S TURTLE	SE	**	S2	G4
NERODIA ERYTHROGASTER NEGLECTA	COPPERBELLY WATER SNAKE	SE	**	S2	G5T2T3
SISTRURUS CATENATUS CATENATUS	EASTERN MASSASAUGA	SE	**	S2	G3G4T3T4
BIRDS					
ACCIPITER COOPERII	COOPER'S HAWK	**	**	S3B,SZN	G5
ACCIPITER STRIATUS	SHARP-SHINNED HAWK	SSC	**	S2B,SZN	G5
AMMODRAMUS HENSLOWII	HENSLOW'S SPARROW	SE	**	S3B,SZN	G4
ARDEA HERODIAS	GREAT BLUE HERON	**	**	S4B,SZN	G5
BARTRAMIA LONGICAUDA	UPLAND SANDPIPER	SE	**	S3B	G5
BOTAURUS LENTIGINOSUS	AMERICAN BITTERN	SE	**	S2B	G4
BUTEO PLATYPTERUS	BROAD-WINGED HAWK	SSC	**	S3B,SRFN	G5
CERTHIA AMERICANA	BROWN CREEPER	**	**	S2B,SZN	G5
CHLIDONIAS NIGER	BLACK TERN	SE	**	S1B,SZN	G4
CISTOTHORUS PALUSTRIS	MARSH WREN	SE	**	S3B,SZN	G5
CISTOTHORUS PLATENSIS	SEDGE WREN	SE	**	S3B,SZN	G5
DENDROICA CERULEA	CERULEAN WARBLER	SSC	**	S3B	G4
IXOBRYCHUS EXILIS	LEAST BITTERN	SE	**	S3B	G5
MNIOTILTA VARIA	BLACK-AND-WHITE WARBLER	SSC	**	S1S2B	G5
RALLUS LIMICOLA	VIRGINIA RAIL	SSC	**	S3B,SZN	G5
MAMMALS					
LUTRA CANADENSIS	NORTHERN RIVER OTTER	SE	**	S?	G5
LYNX RUFUS	BOBCAT	SE	**	S1	G5
MYOTIS SODALIS	INDIANA BAT OR SOCIAL MYOTIS	SE	LE	S1	G2
SPERMOPHILUS FRANKLINII	FRANKLIN'S GROUND SQUIRREL	SE	**	S2	G5
TAXIDEA TAXUS	AMERICAN BADGER	SE	**	S2	G5
HIGH QUALITY NATURAL COMMUNITY					
FOREST - FLOODPLAIN WET-MESIC	WET-MESIC FLOODPLAIN FOREST	SG	**	S3	G3?
FOREST - UPLAND DRY-MESIC	DRY-MESIC UPLAND FOREST	SG	**	S4	G4
FOREST - UPLAND MESIC	MESIC UPLAND FOREST	SG	**	S3	G3?
LAKE - POND	POND	SG	**	S?	

STATE: SX=extirpated, SE=endangered, ST=threatened, SR=rare, SSC=special concern, WL=watch list, SG=significant,** no status but rarity warrants concern

FEDERAL: LE=endangered, LT=threatened, LELT=different listings for specific ranges of species, PE=proposed endangered, PT=proposed threatened, E/SA=appearance similar to LE species, **=not listed

November 16, 1999

ENDANGERED, THREATENED AND RARE SPECIES DOCUMENTED FROM ST. JOSEPH COUNTY, INDIANA

SPECIES NAME	COMMON NAME	STATE	FED	SRANK	GRANK
PRAIRIE - WET	WET PRAIRIE	SG	**	S1	G3
WETLAND - BOG ACID	ACID BOG	SG	**	S2	G3
WETLAND - FEN	FEN	SG	**	S3	G3
WETLAND - FLAT MUCK	MUCK FLAT	SG	**	S2	G2
WETLAND - MARSH	MARSH	SG	**	S4	GU
WETLAND - MEADOW SEDGE	SEDGE MEADOW	SG	**	S1	G3?
WETLAND - SWAMP FOREST	FORESTED SWAMP	SG	**	S2	G2?
WETLAND - SWAMP SHRUB	SHRUB SWAMP	SG	**	S2	GU

STATE: SX=extirpated, SE=endangered, ST=threatened, SR=rare, SSC=special concern, WL=watch list, SG=significant,** no status but rarity warrants concern

FEDERAL: LE=endangered, LT=threatened, LELT=different listings for specific ranges of species, PE=proposed endangered, PT=proposed threatened, E/SA=appearance similar to LE species, **=not listed

APPENDIX E:

MACROINVERTEBRATE DATA SHEETS

PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY

ST. JOSEPH COUNTY, INDIANA

APPENDIX E:

MACROINVERTEBRATE DATA SHEETS

PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY

ST. JOSEPH COUNTY, INDIANA

Table 1. Macroinvertebrate taxa identified at Pleasant and Riddles Lakes watershed stream sites.

Order	Family	Site 2	Site 3	Site 5
Amphipoda	Crangonyctidae	--	--	10
Amphipoda	Talitridae	19	7	--
Bivalvia	Sphaeriidae	--	2	1
Colepotera	Curculionidae	1	--	--
Colepotera	Dytiscidae	3	1	--
Colepotera	Elmidae	1	--	4
Colepotera	Haliplidae	2	8	--
Decopoda	Astacidae	--	--	4
Diptera	Chironomidae	--	--	1
Diptera	Syrphidae	--	1	--
Ephemeroptera	Baetidae	--	--	1
Ephemeroptera	Caenidae	1	--	--
Ephemeroptera	Ephemerellidae	--	--	2
Gastropoda	Lymnaeidae	2	16	--
Gastropoda	Physidae	1	18	3
Gastropoda	Planorbidae	1	--	2
Hempitera	Corixidae	--	7	1
Hempitera	Gerridae	--	--	7
Hempitera	Mesoveliidae	2	4	--
Hempitera	Naucoridae	2	--	--
Hemiptera	Nepidae	--	1	--
Hempitera	Pleidae	7	3	--
Hempitera	Veliidae	--	--	12
Odonata	Aeshnidae	--	--	5
Odonata	Lestidae	6	4	--
Odonata	Libellulidae	1	--	--
Trichoptera	Hydropsychidae	--	--	30
Total Number of Individuals		**49**	**72**	**83**

Table 2. Macroinvertebrate community and mIBI scoring calculation, Heston Ditch.

Order	Family	#	EPT	# w/t	Tolerance (t)	# x t	%
Amphipoda	Talitridae	19		19	8	152	38.78
Colepotera	Curculionidae	1				0	2.04
Colepotera	Dytiscidae	3		3	5	15	6.12
Colepotera	Elmidae	1		1	4	4	2.04
Colepotera	Haliplidae	2		2	7	14	4.08
Ephemeroptera	Caenidae	1	1	1	7	7	2.04
Gastropoda	Lymnaeidae	2		2	6	12	4.08
Gastropoda	Physidae	1		1	8	8	2.04
Gastropoda	Planorbidae	1		1	7	7	2.04
Hempitera	Mesoveliidae	2				0	4.08
Hempitera	Naucoridae	2				0	4.08
Hemiptera	Pleidae	7				0	14.29
Odonata	Lestidae	6		6	9	54	12.24
Odonata	Libellulidae	1		1	9	9	2.04
TOTALS		**49**	**1**	**37**		**282.0**	**100.00**

Table 3. mIBI scoring calculation, Heston Ditch.

mIBI Metric		Metric Score
HBI	7.62	0
Number of Taxa (family)	14	4
Total Count (# individuals)	49	0
% Dominant Taxa	38.8	4
EPT Index (# families)	1	0
EPT Count (# individuals)	1	0
EPT Count/Total Count	0.02	0
EPT Abundance/Chironomid Abundance	max	8
Chironomid Count	0	8
mIBI Score		**2.7**

Table 4. Macroinvertebrate community and mIBI scoring calculation, Bunch Ditch.

Order	Family	#	EPT	# w/t	Tolerance (t)	# x t	%
Amphipoda	Talitridae	7		7	8	56	9.72
Bivalvia	Sphaeriidae	2		2	8	16	2.78
Colepotera	Dytiscidae	1		1	5	5	1.39
Colepotera	Haliplidae	8		8	7	56	11.11
Diptera	Syrphidae	1		1	10	10	1.39
Gastropoda	Lymnaeidae	16		16	6	96	22.22
Gastropoda	Physidae	18		18	8	144	25.00
Hempitera	Corixidae	7		7	10	70	9.72
Hempitera	Mesoveliidae	4				0	5.56
Hemiptera	Nepidae	1				0	1.39
Hemiptera	Pleidae	3				0	4.17
Odonata	Lestidae	4		4	9	36	5.56
TOTALS		**72**	**0**	**64**		**489.0**	**100.00**

Table 5. mIBI scoring calculation, Bunch Ditch.

mIBI Metric		Metric Score
HBI	7.64	0
Number of Taxa (family)	12	4
Total Count (# individuals)	72	0
% Dominant Taxa	25.0	6
EPT Index (# families)	0	0
EPT Count (# individuals)	0	0
EPT Count/Total Count	0.00	0
EPT Abundance/Chironomid Abundance	0.00	0
Chironomid Count	0	8
mIBI Score		**2.0**

Table 6. Macroinvertebrate community and mIBI scoring calculation, Walters Ditch.

Order	Family	#	EPT	# w/t	Tolerance (t)	# x t	%
Acarina	Hydrachridae					0	0.00
Amphipoda	Crangonyctidae	10		10	4	40	12.05
Bivalvia	Sphaeriidae	1		1	8	8	1.20
Colepotera	Elmidae	4		4	4	16	4.82
Decopoda	Astacidae	4		4	8	32	4.82
Diptera	Chironomidae	1		1	6	6	1.20
Ephemeroptera	Baetidae	1	1	1	4	4	1.20
Ephemeroptera	Ephemerellidae	2	2	2	1	2	2.41
Gastropoda	Physidae	3		3	8	24	3.61
Gastropoda	Planorbidae	2		2	7	14	2.41
Hempitera	Corixidae	1		1	10	10	1.20
Hempitera	Gerridae	7		7	5	35	8.43
Hempitera	Veliidae	12				0	14.46
Odonata	Aeshnidae	5		5	3	15	6.02
Trichoptera	Hydropsychidae	30	30	30	4	120	36.14
TOTALS		**83**	**33**	**71**		**326.0**	**100.00**

Table 7. mIBI scoring calculation, Walters Ditch.

mIBI Metric		Metric Score
HBI	4.59	4
Number of Taxa (family)	14	4
Total Count (# individuals)	83	2
% Dominant Taxa	36.1	4
EPT Index (# families)	3	2
EPT Count (# individuals)	33	2
EPT Count/Total Count	0.40	4
EPT Abundance/Chironomid Abundance	33.00	8
Chironomid Count	1	8
mIBI Score		**4.2**

APPENDIX F:

QUALITATIVE HABITAT EVALUATION INDEX (QHEI) DATA SHEETS

PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY

ST. JOSEPH COUNTY, INDIANA

STREAM: Heston Ditch (Site 1) **RIVER MILE:** headwaters **DATE:** 7/19/2005 **QHEI SCORE** 21

1) SUBSTRATE: (Check ONLY Two Substrate Type Boxes: Check all types present)

SUBSTRATE SCORE 1

TYPE			POOL	RIFFLE				POOL	RIFFLE
[ ]	[ ]	BLDER/SLAB(10)			[ ]	[ ]	GRAVEL(7)		
[ ]	[ ]	BOULDER(9)			[ ]	[ ]	SAND(6)		
[ ]	[ ]	COBBLE(8)			[ ]	[ ]	BEDROCK(5)		
[ ]	[ ]	HARDPAN(4)			[ ]	[ ]	DETRITUS(3)		
[X]	[X]	MUCK/SILT(2)			[ ]	[ ]	ARTIFIC(0)		

TOTAL NUMBER OF SUBSTRATE TYPES: [ ] >4(2) [X] <4(0)

SUBSTRATE ORIGIN (all)

[ ] LIMESTONE(1)	[ ] RIP/RAP(0)
[X] TILLS(1)	[ ] HARDPAN(0)
[ ] SANDSTONE(0)	
[ ] SHALE(-1)	
[ ] COAL FINES(-2)	

SILT COVER (one)

[X] SILT-HEAVY(-2)	[ ] SILT-MOD(-1)
[ ] SILT-NORM(0)	[ ] SILT-FREE(1)

Extent of Embeddedness (check one)

[X] EXTENSIVE(-2)	[ ] MODERATE(-1)
[ ] LOW(0)	[ ] NONE(1)

NOTE: (Ignore sludge that originates from point sources: score is based on natural substrates)

COMMENTS:

2) INSTREAM COVER:

COVER SCORE 6

TYPE (Check all that apply)

[ ] UNDERCUT BANKS(1)	[ ] DEEP POOLS(2)	[ ] OXBOWS(1)
[X] OVERHANGING VEGETATION(1)	[ ] ROOTWADS(1)	[ ] AQUATIC MACROPHYTES(1)
[X] SHALLOWS (IN SLOW WATER)(1)	[ ] BOULDERS(1)	[X] LOGS OR WOODY DEBRIS(1)

AMOUNT (Check only one or Check 2 and AVERAGE)

- [ ] EXTENSIVE >75%(11)
- [ ] MODERATE 25-75%(7)
- [X] SPARSE 5-25%(3)
- [ ] NEARLY ABSENT <5%(1)

COMMENTS:

3) CHANNEL MORPHOLOGY: (Check ONLY ONE per Category or Check 2 and AVERAGE)

CHANNEL SCORE 5

SINUOSITY	DEVELOPMENT	CHANNELIZATION	STABILITY
[ ] HIGH(4)	[ ] EXCELLENT(7)	[ ] NONE(6)	[ ] HIGH(3)
[ ] MODERATE(3)	[ ] GOOD(5)	[ ] RECOVERED(4)	[ ] MODERATE(2)
[X] LOW(2)	[ ] FAIR(3)	[ ] RECOVERING(3)	[X] LOW(1)
[ ] NONE(1)	[X] POOR(1)	[X] RECENT OR NO RECOVERY(1)	

MODIFICATION/OTHER

[ ] SNAGGING	[ ] IMPOUND
[ ] RELOCATION	[ ] ISLAND
[ ] CANOPY REMOVAL	[ ] LEVEED
[ ] DREDGING	[ ] BANK SHAPING
[ ] ONE SIDE CHANNEL MODIFICATION	

COMMENTS:

4) RIPARIAN ZONE AND BANK EROSION: (Check ONE box or Check 2 and AVERAGE per bank)

RIPARIAN SCORE 4.5

River Right Looking Downstream

RIPARIAN WIDTH (per bank)

L	R	(per bank)
[ ]	[ ]	WIDE >150 ft.(4)
[ ]	[ ]	MODERATE 30-150 ft.(3)
[ ]	[ ]	NARROW 15-30 ft.(2)
[ ]	[ ]	VERY NARROW 3-15 ft.(1)
[X]	[X]	NONE(0)

EROSION/RUNOFF-FLOODPLAIN QUALITY

L	R	(most predominant per bank)	L	R	(per bank)
[ ]	[ ]	FOREST, SWAMP(3)	[ ]	[ ]	URBAN OR INDUSTRIAL(0)
[ ]	[ ]	OPEN PASTURE/ROW CROP(0)	[X]	[ ]	SHRUB OR OLD FIELD(2)
[ ]	[ ]	RESID.,PARK,NEW FIELD(1)	[ ]	[ ]	CONSERV. TILLAGE(1)
[ ]	[X]	FENCED PASTURE(1)	[ ]	[ ]	MINING/CONSTRUCTION(0)

BANK EROSION

L	R	(per bank)
[X]	[X]	NONE OR LITTLE(3)
[ ]	[ ]	MODERATE(2)
[ ]	[ ]	HEAVY OR SEVERE(1)

COMMENTS:

5) POOL/GLIDE AND RIFFLE/RUN QUALITY

NO POOL = 0 **POOL SCORE** 0

MAX.DEPTH (Check 1)

- [ ] >4 ft.(6)
- [ ] 2.4-4 ft.(4)
- [ ] 1.2-2.4 ft.(2)
- [ ] <1.2 ft.(1)
- [X] <0.6 ft.(Pool=0)(0)

MORPHOLOGY (Check 1)

- [ ] POOL WIDTH>RIFFLE WIDTH(2)
- [ ] POOL WIDTH=RIFFLE WIDTH(1)
- [ ] POOL WIDTH<RIFFLE WIDTH(0)

POOL/RUN/RIFFLE CURRENT VELOCITY (Check all that Apply)

[ ] TORRENTIAL(-1)	[ ] EDDIES(1)
[ ] FAST(1)	[ ] INTERSTITIAL(-1)
[ ] MODERATE(1)	[ ] INTERMITTENT(-2)
[ ] SLOW(1)	

COMMENTS: No pools

RIFFLE SCORE 0

RIFFLE/RUN DEPTH	RIFFLE/RUN SUBSTRATE
[ ] GENERALLY >4 in. MAX.>20 in.(4)	[ ] STABLE (e.g., Cobble,Boulder)(2)
[ ] GENERALLY >4 in. MAX.<20 in.(3)	[ ] MOD.STABLE (e.g., Pea Gravel)(1)
[ ] GENERALLY 2-4 in.(1)	[ ] UNSTABLE (Gravel, Sand)(0)
[X] GENERALLY <2 in.(Riffle=0)(0)	[X] NO RIFFLE(0)

RIFFLE/RUN EMBEDDEDNESS

[ ] EXTENSIVE(-1)	[ ] NONE(2)
[ ] MODERATE(0)	[X] NO RIFFLE(0)
[ ] LOW(1)	

COMMENTS: No riffles

6) GRADIENT (FEET/MILE): 1.92

% POOL ____ % RIFFLE ____ % RUN 100 **GRADIENT SCORE** 4

STREAM: Heston Ditch (Site 2) **RIVER MILE:** Pleasant Lake **DATE:** 7/19/2005 **QHEI SCORE** 28

1) SUBSTRATE: (Check ONLY Two Substrate Type Boxes: Check all types present)

SUBSTRATE SCORE 1

TYPE (Pool)	TYPE (Riffle)		POOL	RIFFLE
[ ]	[ ]	BLDER/SLAB(10)		
[ ]	[ ]	BOULDER(9)		
[ ]	[ ]	COBBLE(8)		
[ ]	[ ]	HARDPAN(4)		
[X]	[X]	MUCK/SILT(2)		
[ ]	[ ]	GRAVEL(7)		
[ ]	[ ]	SAND(6)		
[ ]	[ ]	BEDROCK(5)		
[ ]	[ ]	DETRITUS(3)		
[ ]	[ ]	ARTIFIC(0)		

TOTAL NUMBER OF SUBSTRATE TYPES: [ ] >4(2) [X] <4(0)

NOTE: (Ignore sludge that originates from point sources: score is based on natural substrates)

SUBSTRATE ORIGIN (all)
- [ ] LIMESTONE(1)
- [X] TILLS(1)
- [ ] SANDSTONE(0)
- [ ] SHALE(-1)
- [ ] COAL FINES(-2)
- [ ] RIP/RAP(0)
- [ ] HARDPAN(0)

SILT COVER (one)
- [X] SILT-HEAVY(-2)
- [ ] SILT-MOD(-1)
- [ ] SILT-NORM(0)
- [ ] SILT-FREE(1)

Extent of Embeddedness (check one)
- [X] EXTENSIVE(-2)
- [ ] MODERATE(-1)
- [ ] LOW(0)
- [ ] NONE(1)

COMMENTS:

2) INSTREAM COVER:

COVER SCORE 10

TYPE (Check all that apply)
- [ ] UNDERCUT BANKS(1)
- [X] OVERHANGING VEGETATION(1)
- [X] SHALLOWS (IN SLOW WATER)(1)
- [ ] DEEP POOLS(2)
- [ ] ROOTWADS(1)
- [ ] BOULDERS(1)
- [ ] OXBOWS(1)
- [ ] AQUATIC MACROPHYTES(1)
- [X] LOGS OR WOODY DEBRIS(1)

AMOUNT (Check only one or Check 2 and AVERAGE)
- [ ] EXTENSIVE >75%(11)
- [X] MODERATE 25-75%(7)
- [ ] SPARSE 5-25%(3)
- [ ] NEARLY ABSENT <5%(1)

COMMENTS:

3) CHANNEL MORPHOLOGY: (Check ONLY ONE per Category or Check 2 and AVERAGE)

CHANNEL SCORE 5

SINUOSITY
- [ ] HIGH(4)
- [ ] MODERATE(3)
- [X] LOW(2)
- [ ] NONE(1)

DEVELOPMENT
- [ ] EXCELLENT(7)
- [ ] GOOD(5)
- [ ] FAIR(3)
- [X] POOR(1)

CHANNELIZATION
- [ ] NONE(6)
- [ ] RECOVERED(4)
- [ ] RECOVERING(3)
- [X] RECENT OR NO RECOVERY(1)

STABILITY
- [ ] HIGH(3)
- [ ] MODERATE(2)
- [X] LOW(1)

MODIFICATION/OTHER
- [ ] SNAGGING
- [ ] RELOCATION
- [ ] CANOPY REMOVAL
- [ ] DREDGING
- [ ] ONE SIDE CHANNEL MODIFICATION
- [ ] IMPOUND
- [ ] ISLAND
- [ ] LEVEED
- [ ] BANK SHAPING

COMMENTS:

4) RIPARIAN ZONE AND BANK EROSION: (Check ONE box or Check 2 and AVERAGE per bank)

RIPARIAN SCORE 8

River Right Looking Downstream

RIPARIAN WIDTH (per bank)

L	R	(per bank)
[ ]	[ ]	WIDE >150 ft.(4)
[ ]	[X]	MODERATE 30-150 ft.(3)
[X]	[ ]	NARROW 15-30 ft.(2)
[ ]	[ ]	VERY NARROW 3-15 ft.(1)
[ ]	[ ]	NONE(0)

EROSION/RUNOFF-FLOODPLAIN QUALITY

L	R	(most predominant per bank)	L	R	(per bank)
[X]	[X]	FOREST, SWAMP(3)	[ ]	[ ]	URBAN OR INDUSTRIAL(0)
[ ]	[ ]	OPEN PASTURE/ROW CROP(0)	[X]	[X]	SHRUB OR OLD FIELD(2)
[ ]	[ ]	RESID.,PARK,NEW FIELD(1)	[ ]	[ ]	CONSERV. TILLAGE(1)
[ ]	[ ]	FENCED PASTURE(1)	[ ]	[ ]	MINING/CONSTRUCTION(0)

BANK EROSION

L	R	(per bank)
[X]	[X]	NONE OR LITTLE(3)
[ ]	[ ]	MODERATE(2)
[ ]	[ ]	HEAVY OR SEVERE(1)

COMMENTS:

5) POOL/GLIDE AND RIFFLE/RUN QUALITY

NO POOL = 0 **POOL SCORE** 0

MAX.DEPTH (Check 1)
- [ ] >4 ft.(6)
- [ ] 2.4-4 ft.(4)
- [ ] 1.2-2.4 ft.(2)
- [ ] <1.2 ft.(1)
- [X] <0.6 ft.(Pool=0)(0)

MORPHOLOGY (Check 1)
- [ ] POOL WIDTH>RIFFLE WIDTH(2)
- [ ] POOL WIDTH=RIFFLE WIDTH(1)
- [ ] POOL WIDTH<RIFFLE WIDTH(0)

POOL/RUN/RIFFLE CURRENT VELOCITY (Check all that Apply)
- [ ] TORRENTIAL(-1)
- [ ] FAST(1)
- [ ] MODERATE(1)
- [ ] SLOW(1)
- [ ] EDDIES(1)
- [ ] INTERSTITIAL(-1)
- [ ] INTERMITTENT(-2)

COMMENTS: No pools

RIFFLE SCORE 0

RIFFLE/RUN DEPTH
- [ ] GENERALLY >4 in. MAX.>20 in.(4)
- [ ] GENERALLY >4 in. MAX.<20 in.(3)
- [ ] GENERALLY 2-4 in.(1)
- [X] GENERALLY <2 in.(Riffle=0)(0)

RIFFLE/RUN SUBSTRATE
- [ ] STABLE (e.g., Cobble,Boulder)(2)
- [ ] MOD.STABLE (e.g., Pea Gravel)(1)
- [ ] UNSTABLE (Gravel, Sand)(0)
- [X] NO RIFFLE(0)

RIFFLE/RUN EMBEDDEDNESS
- [ ] EXTENSIVE(-1)
- [ ] MODERATE(0)
- [ ] LOW(1)
- [ ] NONE(2)
- [X] NO RIFFLE(0)

COMMENTS: No riffles

6) GRADIENT (FEET/MILE): 2.64

% POOL ______ % RIFFLE ______ % RUN 100 **GRADIENT SCORE** 4

STREAM: Bunch Ditch (Site 3) **RIVER MILE:** ______ **DATE:** 7/19/2005 **QHEI SCORE** 45

1) SUBSTRATE: (Check ONLY Two Substrate Type Boxes: Check all types present) **SUBSTRATE SCORE** 7

TYPE			POOL	RIFFLE			TYPE	POOL	RIFFLE
[ ]	[ ]	BLDER/SLAB(10)			[ ]	[ ]	GRAVEL(7)	X	
[ ]	[ ]	BOULDER(9)			[ ]	[X]	SAND(6)	X	
[ ]	[ ]	COBBLE(8)			[ ]	[ ]	BEDROCK(5)		
[ ]	[ ]	HARDPAN(4)			[ ]	[ ]	DETRITUS(3)	X	
[ ]	[X]	MUCK/SILT(2)	X		[ ]	[ ]	ARTIFIC(0)		

TOTAL NUMBER OF SUBSTRATE TYPES: [ ] >4(2) [ ] <4(0)

SUBSTRATE ORIGIN (all): [ ] LIMESTONE(1) [X] TILLS(1) [ ] SANDSTONE(0) [ ] SHALE(-1) [ ] COAL FINES(-2) [ ] RIP/RAP(0) [ ] HARDPAN(0)

SILT COVER (one): [ ] SILT-HEAVY(-2) [X] SILT-MOD(-1) [ ] SILT-NORM(0) [ ] SILT-FREE(1)

Extent of Embeddedness (check one): [ ] EXTENSIVE(-2) [X] MODERATE(-1) [ ] LOW(0) [ ] NONE(1)

NOTE: (Ignore sludge that originates from point sources: score is based on natural substrates)

COMMENTS:

2) INSTREAM COVER: **COVER SCORE** 11

TYPE (Check all that apply): [ ] UNDERCUT BANKS(1) [X] OVERHANGING VEGETATION(1) [X] SHALLOWS (IN SLOW WATER)(1) [ ] DEEP POOLS(2) [ ] ROOTWADS(1) [ ] BOULDERS(1) [ ] OXBOWS(1) [X] AQUATIC MACROPHYTES(1) [X] LOGS OR WOODY DEBRIS(1)

AMOUNT (Check only one or Check 2 and AVERAGE): [ ] EXTENSIVE >75%(11) [X] MODERATE 25-75%(7) [ ] SPARSE 5-25%(3) [ ] NEARLY ABSENT <5%(1)

COMMENTS: Dominated by floating macrophytes

3) CHANNEL MORPHOLOGY: (Check ONLY ONE per Category or Check 2 and AVERAGE) **CHANNEL SCORE** 8

SINUOSITY: [ ] HIGH(4) [ ] MODERATE(3) [X] LOW(2) [ ] NONE(1)

DEVELOPMENT: [ ] EXCELLENT(7) [ ] GOOD(5) [ ] FAIR(3) [X] POOR(1)

CHANNELIZATION: [ ] NONE(6) [ ] RECOVERED(4) [X] RECOVERING(3) [ ] RECENT OR NO RECOVERY(1)

STABILITY: [ ] HIGH(3) [X] MODERATE(2) [ ] LOW(1)

MODIFICATION/OTHER: [ ] SNAGGING [ ] RELOCATION [ ] CANOPY REMOVAL [ ] DREDGING [ ] ONE SIDE CHANNEL MODIFICATION [ ] IMPOUND [ ] ISLAND [ ] LEVEED [ ] BANK SHAPING

COMMENTS:

4) RIPARIAN ZONE AND BANK EROSION: (Check ONE box or Check 2 and AVERAGE per bank) **RIPARIAN SCORE** 9

River Right Looking Downstream

RIPARIAN WIDTH (per bank) (L / R): [X][ ] WIDE >150 ft.(4); [ ][X] MODERATE 30-150 ft.(3); [ ][ ] NARROW 15-30 ft.(2); [ ][ ] VERY NARROW 3-15 ft.(1); [ ][ ] NONE(0)

EROSION/RUNOFF-FLOODPLAIN QUALITY (most predominant per bank) (L / R): [X][ ] FOREST, SWAMP(3); [ ][ ] OPEN PASTURE/ROW CROP(0); [ ][ ] RESID.,PARK,NEW FIELD(1); [ ][ ] FENCED PASTURE(1); [ ][ ] URBAN OR INDUSTRIAL(0); [ ][X] SHRUB OR OLD FIELD(2); [ ][ ] CONSERV. TILLAGE(1); [ ][ ] MINING/CONSTRUCTION(0)

BANK EROSION (per bank) (L / R): [X][X] NONE OR LITTLE(3); [ ][ ] MODERATE(2); [ ][ ] HEAVY OR SEVERE(1)

COMMENTS:

5) POOL/GLIDE AND RIFFLE/RUN QUALITY **NO POOL = 0** **POOL SCORE** 4

MAX.DEPTH (Check 1): [ ] >4 ft.(6) [ ] 2.4-4 ft.(4) [ ] 1.2-2.4 ft.(2) [X] <1.2 ft.(1) [ ] <0.6 ft.(Pool=0)(0)

MORPHOLOGY (Check 1): [X] POOL WIDTH>RIFFLE WIDTH(2) [ ] POOL WIDTH=RIFFLE WIDTH(1) [ ] POOL WIDTH<RIFFLE WIDTH(0)

POOL/RUN/RIFFLE CURRENT VELOCITY (Check all that Apply): [ ] TORRENTIAL(-1) [ ] FAST(1) [ ] MODERATE(1) [X] SLOW(1) [ ] EDDIES(1) [ ] INTERSTITIAL(-1) [ ] INTERMITTENT(-2)

COMMENTS:

RIFFLE SCORE 0

RIFFLE/RUN DEPTH: [ ] GENERALLY >4 in. MAX.>20 in.(4) [ ] GENERALLY >4 in. MAX.<20 in.(3) [ ] GENERALLY 2-4 in.(1) [X] GENERALLY <2 in.(Riffle=0)(0)

RIFFLE/RUN SUBSTRATE: [ ] STABLE (e.g., Cobble,Boulder)(2) [ ] MOD.STABLE (e.g., Pea Gravel)(1) [ ] UNSTABLE (Gravel, Sand)(0) [X] NO RIFFLE(0)

RIFFLE/RUN EMBEDDEDNESS: [ ] EXTENSIVE(-1) [ ] MODERATE(0) [ ] LOW(1) [ ] NONE(2) [X] NO RIFFLE(0)

COMMENTS: No riffles

6) GRADIENT (FEET/MILE): 5.87 **% POOL** 5 **% RIFFLE** ____ **% RUN** 95 **GRADIENT SCORE** 6

STREAM: Heston Ditch (Site 4) **RIVER MILE:** btw lakes **DATE:** 7/19/2005 **QHEI SCORE** 32

1) SUBSTRATE: (Check ONLY Two Substrate Type Boxes: Check all types present) **SUBSTRATE SCORE** 1

TYPE

Pool	Riffle	Type	Pool	Riffle
[ ]	[ ]	BLDER/SLAB(10)		
[ ]	[ ]	BOULDER(9)		
[ ]	[ ]	COBBLE(8)		
[ ]	[ ]	HARDPAN(4)		
[X]	[X]	MUCK/SILT(2)		
[ ]	[ ]	GRAVEL(7)		
[ ]	[ ]	SAND(6)		
[ ]	[ ]	BEDROCK(5)		
[ ]	[ ]	DETRITUS(3)		
[ ]	[ ]	ARTIFIC(0)		

TOTAL NUMBER OF SUBSTRATE TYPES: [ ] >4(2) [X] <4(0)

SUBSTRATE ORIGIN (all)
- [ ] LIMESTONE(1)
- [X] TILLS(1)
- [ ] SANDSTONE(0)
- [ ] SHALE(-1)
- [ ] COAL FINES(-2)
- [ ] RIP/RAP(0)
- [ ] HARDPAN(0)

SILT COVER (one)
- [X] SILT-HEAVY(-2)
- [ ] SILT-NORM(0)
- [ ] SILT-MOD(-1)
- [ ] SILT-FREE(1)

Extent of Embeddedness (check one)
- [X] EXTENSIVE(-2)
- [ ] LOW(0)
- [ ] MODERATE(-1)
- [ ] NONE(1)

NOTE: (Ignore sludge that originates from point sources: score is based on natural substrates)

COMMENTS:

2) INSTREAM COVER: **COVER SCORE** 11

TYPE (Check all that apply)
- [ ] UNDERCUT BANKS(1)
- [X] OVERHANGING VEGETATION(1)
- [X] SHALLOWS (IN SLOW WATER)(1)
- [X] DEEP POOLS(2)
- [ ] ROOTWADS(1)
- [ ] BOULDERS(1)
- [ ] OXBOWS(1)
- [X] AQUATIC MACROPHYTES(1)
- [X] LOGS OR WOODY DEBRIS(1)

AMOUNT (Check only one or Check 2 and AVERAGE)
- [ ] EXTENSIVE >75%(11)
- [X] MODERATE 25-75%(7)
- [ ] SPARSE 5-25%(3)
- [ ] NEARLY ABSENT <5%(1)

COMMENTS:

3) CHANNEL MORPHOLOGY: (Check ONLY ONE per Category or Check 2 and AVERAGE) **CHANNEL SCORE** 8

SINUOSITY
- [ ] HIGH(4)
- [ ] MODERATE(3)
- [X] LOW(2)
- [ ] NONE(1)

DEVELOPMENT
- [ ] EXCELLENT(7)
- [ ] GOOD(5)
- [ ] FAIR(3)
- [X] POOR(1)

CHANNELIZATION
- [ ] NONE(6)
- [ ] RECOVERED(4)
- [X] RECOVERING(3)
- [ ] RECENT OR NO RECOVERY(1)

STABILITY
- [ ] HIGH(3)
- [X] MODERATE(2)
- [ ] LOW(1)

MODIFICATION/OTHER
- [ ] SNAGGING
- [ ] RELOCATION
- [ ] CANOPY REMOVAL
- [ ] DREDGING
- [ ] ONE SIDE CHANNEL MODIFICATION
- [ ] IMPOUND
- [ ] ISLAND
- [ ] LEVEED
- [ ] BANK SHAPING

COMMENTS:

4) RIPARIAN ZONE AND BANK EROSION: (Check ONE box or Check 2 and AVERAGE per bank) **RIPARIAN SCORE** 10

River Right Looking Downstream

RIPARIAN WIDTH (per bank)

L	R	(per bank)
[X]	[X]	WIDE >150 ft.(4)
[ ]	[ ]	MODERATE 30-150 ft.(3)
[ ]	[ ]	NARROW 15-30 ft.(2)
[ ]	[ ]	VERY NARROW 3-15 ft.(1)
[ ]	[ ]	NONE(0)

EROSION/RUNOFF-FLOODPLAIN QUALITY

L	R	(most predominant per bank)	L	R	(per bank)
[X]	[X]	FOREST, SWAMP(3)	[ ]	[ ]	URBAN OR INDUSTRIAL(0)
[ ]	[ ]	OPEN PASTURE/ROW CROP(0)	[ ]	[ ]	SHRUB OR OLD FIELD(2)
[ ]	[ ]	RESID.,PARK,NEW FIELD(1)	[ ]	[ ]	CONSERV. TILLAGE(1)
[ ]	[ ]	FENCED PASTURE(1)	[ ]	[ ]	MINING/CONSTRUCTION(0)

BANK EROSION

L	R	(per bank)
[X]	[X]	NONE OR LITTLE(3)
[ ]	[ ]	MODERATE(2)
[ ]	[ ]	HEAVY OR SEVERE(1)

COMMENTS:

5) POOL/GLIDE AND RIFFLE/RUN QUALITY **NO POOL = 0** **POOL SCORE** 0

MAX.DEPTH (Check 1)
- [ ] >4 ft.(6)
- [ ] 2.4-4 ft.(4)
- [ ] 1.2-2.4 ft.(2)
- [ ] <1.2 ft.(1)
- [X] <0.6 ft.(Pool=0)(0)

MORPHOLOGY (Check 1)
- [ ] POOL WIDTH>RIFFLE WIDTH(2)
- [ ] POOL WIDTH=RIFFLE WIDTH(1)
- [ ] POOL WIDTH<RIFFLE WIDTH(0)

POOL/RUN/RIFFLE CURRENT VELOCITY (Check all that Apply)
- [ ] TORRENTIAL(-1)
- [ ] FAST(1)
- [ ] MODERATE(1)
- [ ] SLOW(1)
- [ ] EDDIES(1)
- [ ] INTERSTITIAL(-1)
- [ ] INTERMITTENT(-2)

COMMENTS: No pools

RIFFLE SCORE 0

RIFFLE/RUN DEPTH
- [ ] GENERALLY >4 in. MAX.>20 in.(4)
- [ ] GENERALLY >4 in. MAX.<20 in.(3)
- [ ] GENERALLY 2-4 in.(1)
- [X] GENERALLY <2 in.(Riffle=0)(0)

RIFFLE/RUN SUBSTRATE
- [ ] STABLE (e.g., Cobble,Boulder)(2)
- [ ] MOD.STABLE (e.g., Pea Gravel)(1)
- [ ] UNSTABLE (Gravel, Sand)(0)
- [X] NO RIFFLE(0)

RIFFLE/RUN EMBEDDEDNESS
- [ ] EXTENSIVE(-1)
- [ ] MODERATE(0)
- [ ] LOW(1)
- [ ] NONE(2)
- [X] NO RIFFLE(0)

COMMENTS: No riffles

6) GRADIENT (FEET/MILE): 0 **% POOL** ____ **% RIFFLE** ____ **% RUN** 100 **GRADIENT SCORE** 2

STREAM: Walters Ditch (Site 5) **RIVER MILE:** ______ **DATE:** 7/19/2005 **QHEI SCORE** 42

1) SUBSTRATE: (Check ONLY Two Substrate Type Boxes: Check all types present) **SUBSTRATE SCORE** 2

TYPE			POOL	RIFFLE				POOL	RIFFLE
[ ]	[ ]	BLDER/SLAB(10)			[ ]	[ ]	GRAVEL(7)		
[ ]	[ ]	BOULDER(9)			[ ]	[ ]	SAND(6)		
[ ]	[ ]	COBBLE(8)			[ ]	[ ]	BEDROCK(5)		
[ ]	[ ]	HARDPAN(4)			[ ]	[ ]	DETRITUS(3)	X	X
[X]	[X]	MUCK/SILT(2)	X	X	[ ]	[ ]	ARTIFIC(0)	X	X

TOTAL NUMBER OF SUBSTRATE TYPES: [ ] >4(2) [X] <4(0)

SUBSTRATE ORIGIN (all)
- [ ] LIMESTONE(1)
- [X] TILLS(1)
- [ ] SANDSTONE(0)
- [ ] SHALE(-1)
- [ ] COAL FINES(-2)
- [ ] RIP/RAP(0)
- [ ] HARDPAN(0)

SILT COVER (one)
- [X] SILT-HEAVY(-2)
- [ ] SILT-MOD(-1)
- [ ] SILT-NORM(0)
- [ ] SILT-FREE(1)

Extent of Embeddedness (check one)
- [ ] EXTENSIVE(-2)
- [X] MODERATE(-1)
- [ ] LOW(0)
- [ ] NONE(1)

NOTE: (Ignore sludge that originates from point sources: score is based on natural substrates)

COMMENTS:

2) INSTREAM COVER: **COVER SCORE** 13

TYPE (Check all that apply)
- [X] UNDERCUT BANKS(1)
- [X] OVERHANGING VEGETATION(1)
- [X] SHALLOWS (IN SLOW WATER)(1)
- [ ] DEEP POOLS(2)
- [X] ROOTWADS(1)
- [ ] BOULDERS(1)
- [ ] OXBOWS(1)
- [X] AQUATIC MACROPHYTES(1)
- [X] LOGS OR WOODY DEBRIS(1)

AMOUNT (Check only one or Check 2 and AVERAGE)
- [ ] EXTENSIVE >75%(11)
- [X] MODERATE 25-75%(7)
- [ ] SPARSE 5-25%(3)
- [ ] NEARLY ABSENT <5%(1)

COMMENTS:

3) CHANNEL MORPHOLOGY: (Check ONLY ONE per Category or Check 2 and AVERAGE) **CHANNEL SCORE** 8

SINUOSITY
- [ ] HIGH(4)
- [ ] MODERATE(3)
- [X] LOW(2)
- [ ] NONE(1)

DEVELOPMENT
- [ ] EXCELLENT(7)
- [ ] GOOD(5)
- [ ] FAIR(3)
- [X] POOR(1)

CHANNELIZATION
- [ ] NONE(6)
- [ ] RECOVERED(4)
- [X] RECOVERING(3)
- [ ] RECENT OR NO RECOVERY(1)

STABILITY
- [ ] HIGH(3)
- [X] MODERATE(2)
- [ ] LOW(1)

MODIFICATION/OTHER
- [ ] SNAGGING
- [ ] RELOCATION
- [ ] CANOPY REMOVAL
- [ ] DREDGING
- [ ] ONE SIDE CHANNEL MODIFICATION
- [ ] IMPOUND
- [ ] ISLAND
- [ ] LEVEED
- [ ] BANK SHAPING

COMMENTS:

4) RIPARIAN ZONE AND BANK EROSION: (Check ONE box or Check 2 and AVERAGE per bank) **RIPARIAN SCORE** 9

River Right Looking Downstream

RIPARIAN WIDTH (per bank)

L	R	(per bank)
[ ]	[X]	WIDE >150 ft.(4)
[ ]	[ ]	MODERATE 30-150 ft.(3)
[X]	[ ]	NARROW 15-30 ft.(2)
[ ]	[ ]	VERY NARROW 3-15 ft.(1)
[ ]	[ ]	NONE(0)

EROSION/RUNOFF-FLOODPLAIN QUALITY

L	R	(most predominant per bank)	L	R	(per bank)
[X]	[X]	FOREST, SWAMP(3)	[ ]	[ ]	URBAN OR INDUSTRIAL(0)
[ ]	[ ]	OPEN PASTURE/ROW CROP(0)	[ ]	[ ]	SHRUB OR OLD FIELD(2)
[ ]	[ ]	RESID.,PARK,NEW FIELD(1)	[ ]	[ ]	CONSERV. TILLAGE(1)
[ ]	[ ]	FENCED PASTURE(1)	[ ]	[ ]	MINING/CONSTRUCTION(0)

BANK EROSION

L	R	(per bank)
[X]	[X]	NONE OR LITTLE(3)
[ ]	[ ]	MODERATE(2)
[ ]	[ ]	HEAVY OR SEVERE(1)

COMMENTS:

5) POOL/GLIDE AND RIFFLE/RUN QUALITY **NO POOL = 0** **POOL SCORE** 4

MAX.DEPTH (Check 1)
- [ ] >4 ft.(6)
- [ ] 2.4-4 ft.(4)
- [ ] 1.2-2.4 ft.(2)
- [X] <1.2 ft.(1)
- [ ] <0.6 ft.(Pool=0)(0)

MORPHOLOGY (Check 1)
- [X] POOL WIDTH>RIFFLE WIDTH(2)
- [ ] POOL WIDTH=RIFFLE WIDTH(1)
- [ ] POOL WIDTH<RIFFLE WIDTH(0)

POOL/RUN/RIFFLE CURRENT VELOCITY (Check all that Apply)
- [ ] TORRENTIAL(-1)
- [ ] FAST(1)
- [ ] MODERATE(1)
- [X] SLOW(1)
- [ ] EDDIES(1)
- [ ] INTERSTITIAL(-1)
- [ ] INTERMITTENT(-2)

COMMENTS:

RIFFLE SCORE 0

RIFFLE/RUN DEPTH
- [ ] GENERALLY >4 in. MAX.>20 in.(4)
- [ ] GENERALLY >4 in. MAX.<20 in.(3)
- [ ] GENERALLY 2-4 in.(1)
- [X] GENERALLY <2 in.(Riffle=0)(0)

RIFFLE/RUN SUBSTRATE
- [ ] STABLE (e.g., Cobble,Boulder)(2)
- [ ] MOD.STABLE (e.g., Pea Gravel)(1)
- [ ] UNSTABLE (Gravel, Sand)(0)
- [ ] NO RIFFLE(0)

RIFFLE/RUN EMBEDDEDNESS
- [ ] EXTENSIVE(-1)
- [ ] MODERATE(0)
- [ ] LOW(1)
- [ ] NONE(2)
- [ ] NO RIFFLE(0)

COMMENTS:

6) GRADIENT (FEET/MILE): 3.39 **% POOL** 10 **% RIFFLE** 10 **% RUN** 80 **GRADIENT SCORE** 4

APPENDIX G:

CURRENT WATER QUALITY DATA COMPARED TO MEDIAN VALUES FOR INDIANA LAKES

PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY

ST. JOSEPH COUNTY, INDIANA

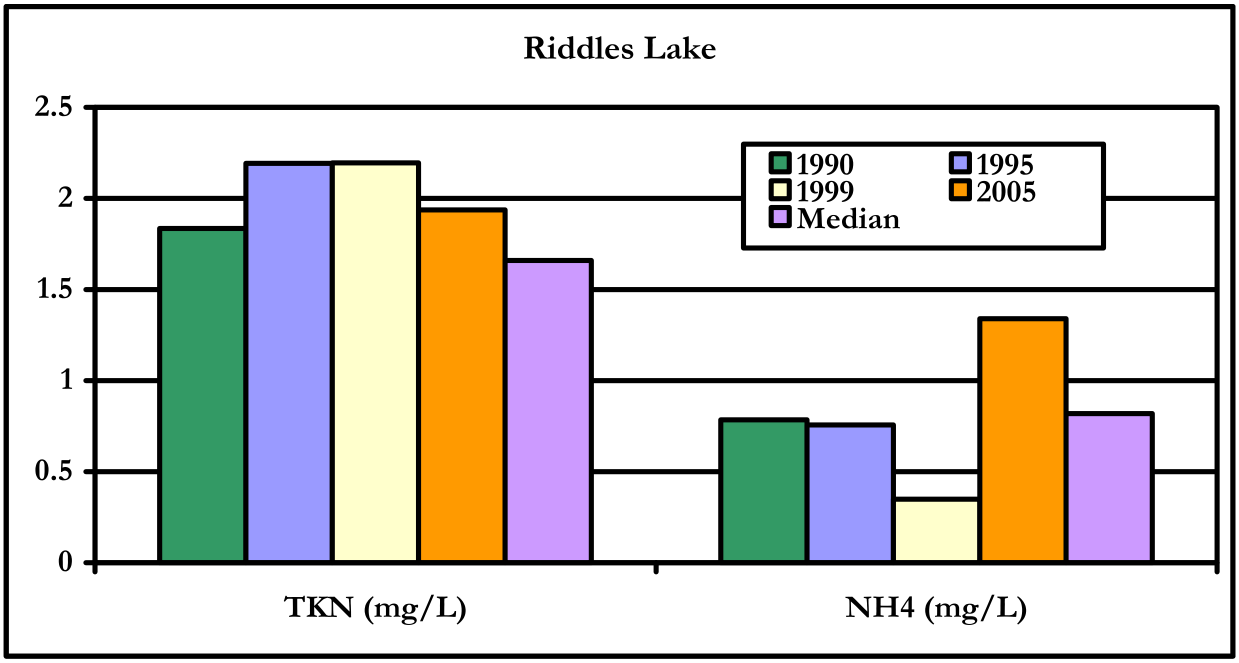


Figure 1. Comparison of Riddles Lake total Kjeldahl nitrogen and ammonia-nitrogen concentrations over time with the median concentrations for Indiana lakes.

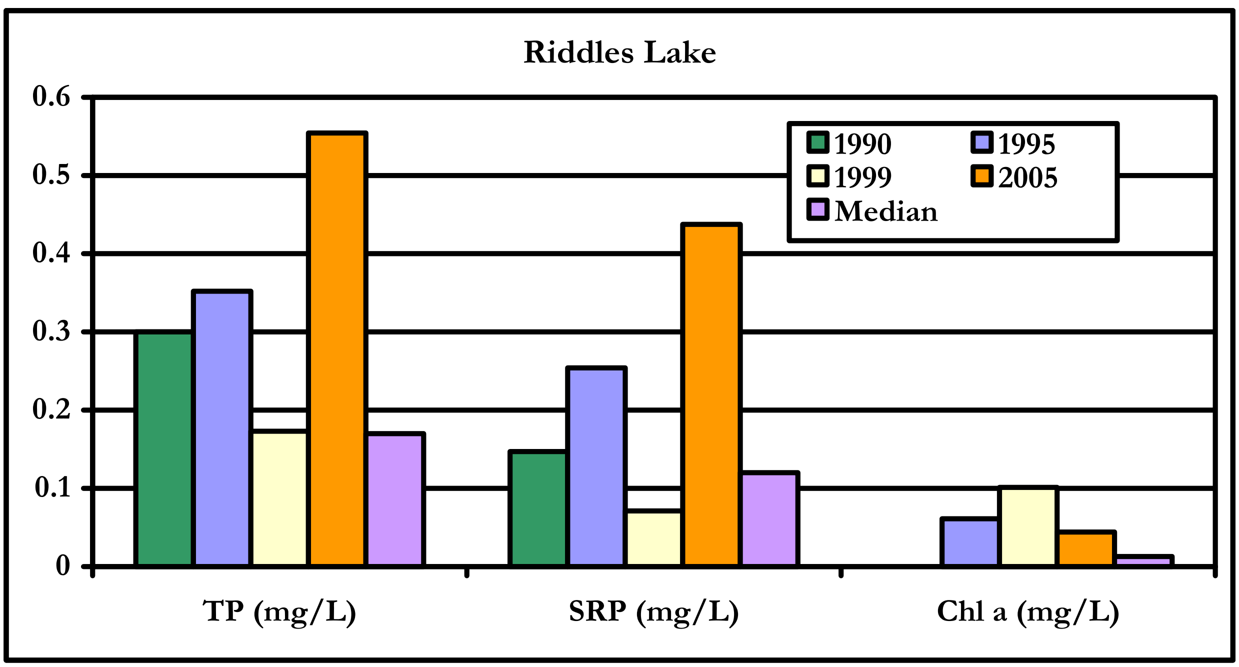


Figure 2. Comparison of Riddles Lake total phosphorus, soluble reactive phosphorus, and chlorophyll *a* concentrations over time with the median concentrations for Indiana lakes.

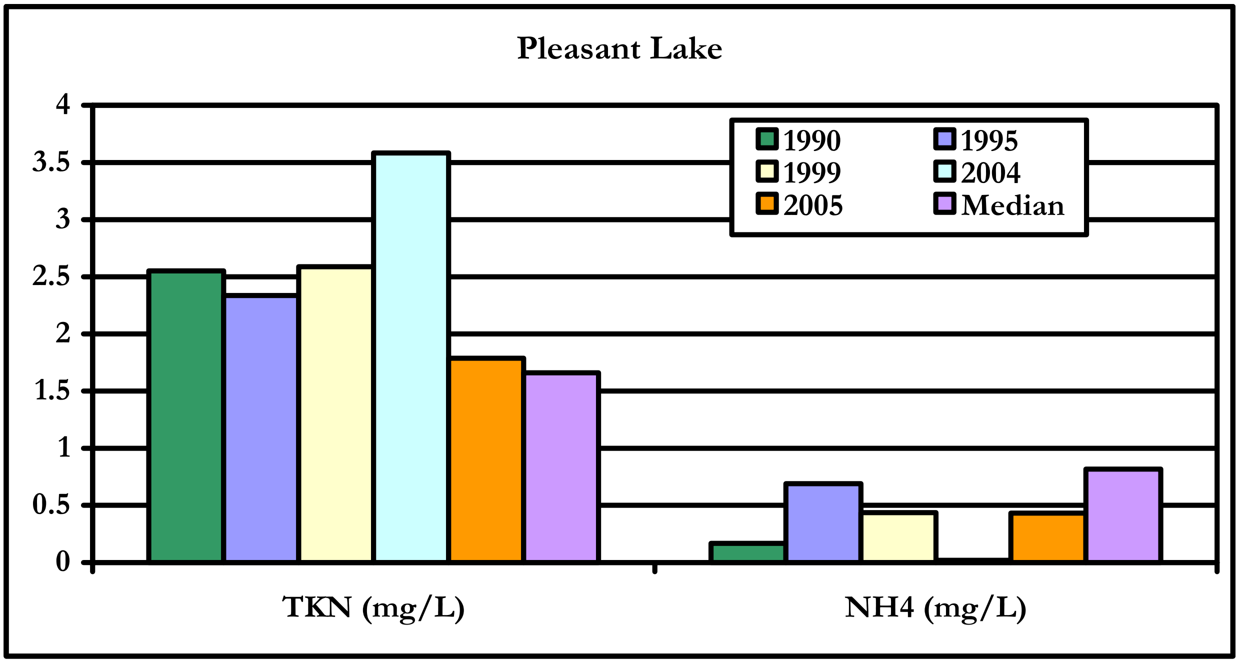


Figure 3. Comparison of Pleasant Lake total Kjeldahl nitrogen and ammonia-nitrogen concentrations over time with the median concentrations for Indiana lakes.

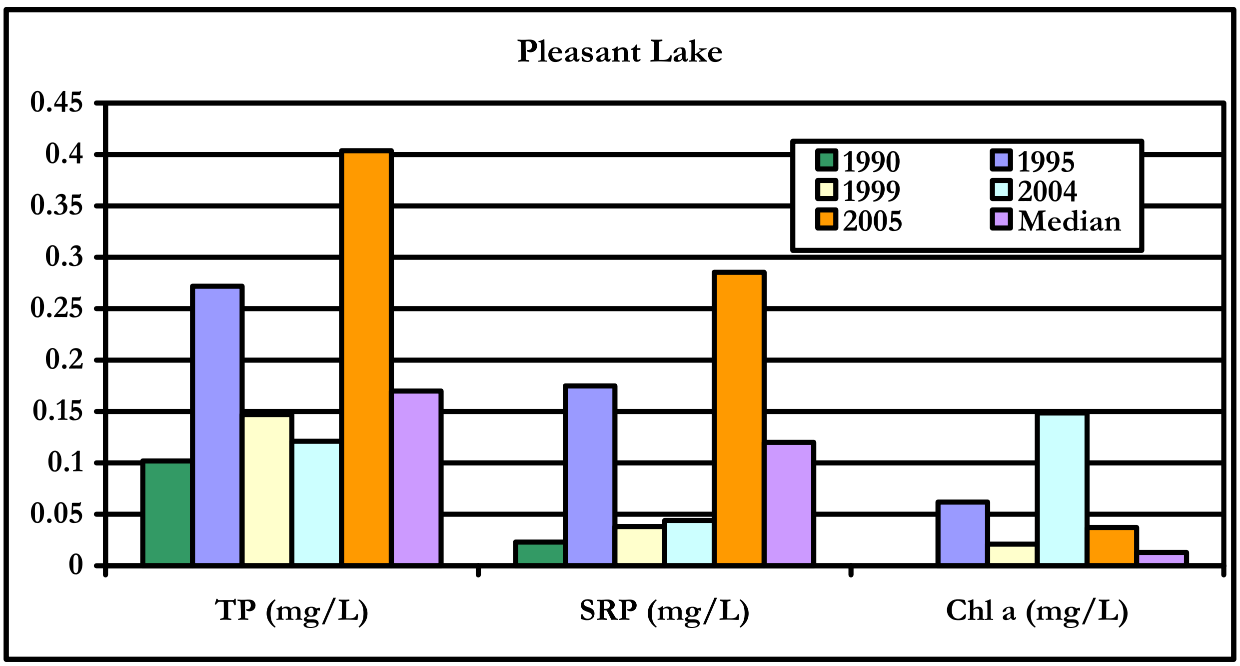


Figure 4. Comparison of Pleasant Lake total phosphorus, soluble reactive phosphorus, and chlorophyll *a* concentrations over time with the median concentrations for Indiana lakes.

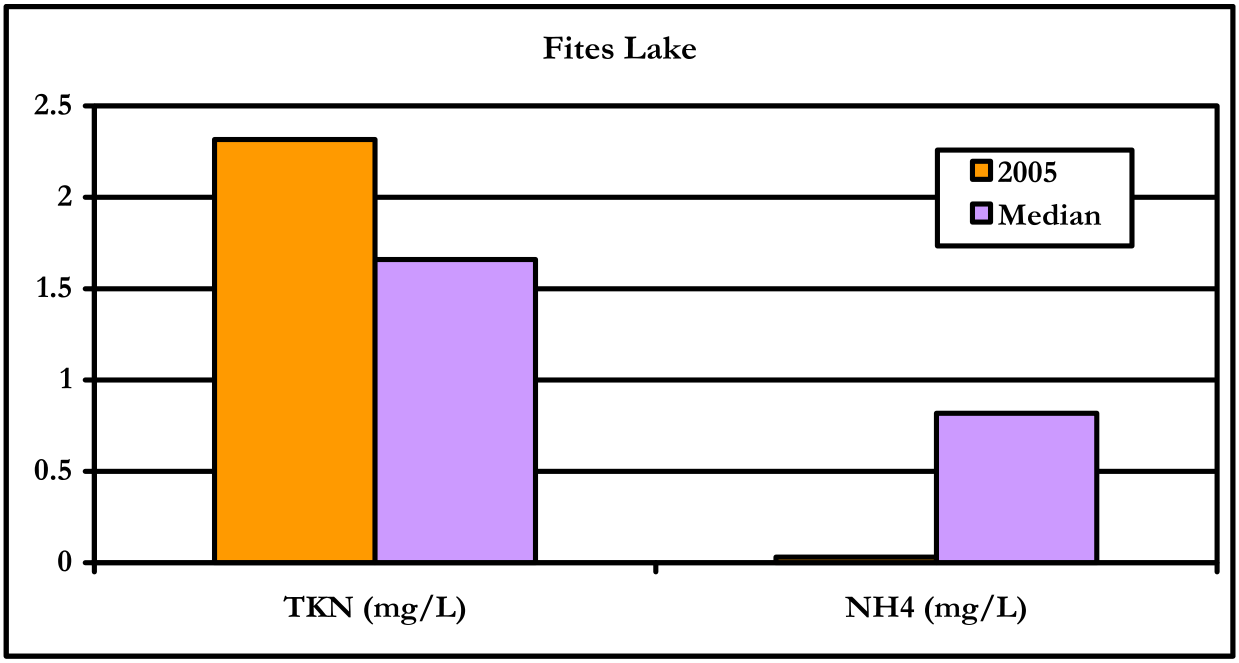


Figure 5. Comparison of Fites Lake total Kjeldahl nitrogen and ammonia-nitrogen concentrations over time with the median concentrations for Indiana lakes.

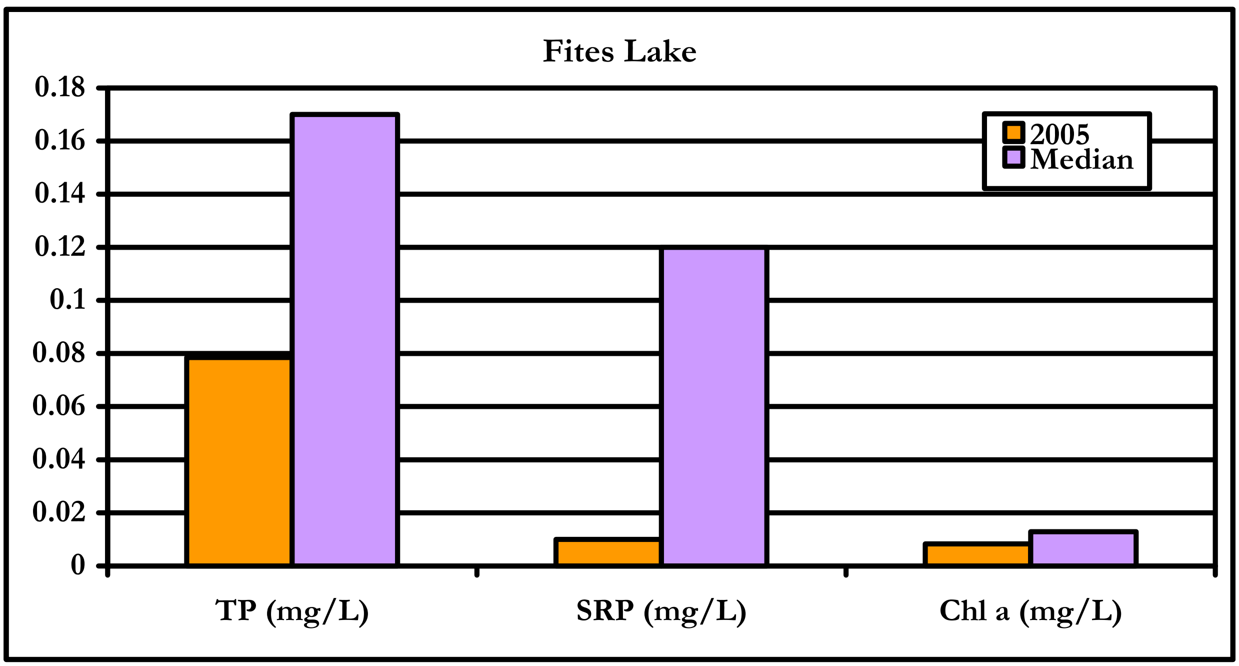


Figure 6. Comparison of Fites Lake total phosphorus, soluble reactive phosphorus, and chlorophyll *a* concentrations over time with the median concentrations for Indiana lakes.

APPENDIX H:

MACROPHYTE SURVEY

PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY

ST. JOSEPH COUNTY, INDIANA

Aquatic Vegetation Reconnaissance Sampling

Waterbody Cover Sheet

Surveying Organization: JFNew

Waterbody Name: Riddles Lake

Lake ID:

County: St. Joseph

Date: 7/27/05

Habitat Stratum: IL

Ave. Lake Depth (ft): 8 ft

Lake Level:

GPS Metadata

Crew Leader: S. Peel

Datum:	Zone:	Accuracy:
NAD 83	16N	<1 m

Recorder: S. Namestnik

Method: Trimble PRO XRS

Secchi Depth (ft): 1.7 ft

Total # of Plant Beds Surveyed: 4

Total # of Species: 40

Littoral Zone Size (acres): 28.7 ac

- ☐ Measured
- ✓ Estimated

Littoral Zone Max. Depth (ft): 5.1 ft

- ☐ Measured
- ☐ Estimate (historical Secchi)
- ✓ Estimated (current Secchi)

Notable Conditions:

Abbreviation	Scientific Name	Common Name	Stratum
ALISUB	*Alisma subcordatum*	Common water plantain	Emergent
BIDCER	*Bidens cernua*	Nodding bur marigold	Emergent
BOECYC	*Boehmeria cylindrica*	False nettle	Emergent
CEPOCC	*Cephalanthus occidentalis*	Buttonbush	Emergent
CERDEM	*Ceratophyllum demersum*	Coontail	Submergent
CICBUL	*Cicuta bulbifera*	Bulblet-bearing water helmo	Emergent
DECVER	*Decodon verticillatus*	Whirled loosestrife	Emergent
ECHCRU	*Echinochloa crusgalli*	Barnyard grass	Emergent
ELEACI	*Eleocharis acicularis*	Needle spike rush	Emergent
ELONUT	*Elodea nuttallii*	Slender water weed	Submergent
FILALG	*Filamentous algae*	Filamentous algae	Algae
IMPCAP	*Impatiens capensis*	Spotted touch-me-not	Emergent
LEEORY	*Leersia oryzoides*	Rice cut grass	Emergent
LEMMIO	*Lemna minor*	Common duckweed	Floating
LEMTRI	*Lemna trisulca*	Star duckweed	Floating
LYCAME	*Lycopus americanus*	Common water horehound	Emergent
LYTSAL	*Lythrum salicaria*	Purple loosestrife	Emergent
MYRSPI	*Myriophyllum spicatum*	Eurasian water milfoil	Submergent
NAJGUA	*Najas guadalupensis*	Southern naiad	Submergent
NUPADV	*Nuphar advena*	Spatterdock	Floating
NYMTUB	*Nyphaea tuberosa*	White water lily	Floating
PELVIR	*Peltandra virginica*	Arrow arum	Emergent
PHAARU	*Phalarus arundinacaea*	Reed canary grass	Emergent
PILPUM	*Pilea pumila*	Clearweed	Emergent
POLCOC	*Polygonum coccineum*	Water heartsease	Emergent
POLLAP	*Polygonum lapathifolia*	Nodding smartweed	Emergent
POLPER	*Polygonum persicaria*	Lady's thumbprint	Emergent
PONCOR	*Pontedaria cordata*	Pickerel weed	Emergent
POTCRI	*Potamogeton crispus*	Curly leaf pondweed	Submergent
POTFOL	*Potamogeton foliosis*	Leafy pondweed	Submergent
RUM SP	*Rumex species*	Dock species	Emergent
SAGLAT	*Sagittaria latifolia*	Common arrowhead	Emergent
SCIPUN	*Scirpus pungens*	Chairmakers rush	Emergent
SCIVAL	*Scirpus validus*	Softstem bulrush	Emergent
SPAEUR	*Sparganeum eurycarpum*	Common burreed	Emergent
SPIPOL	*Spirodela polyrhiza*	Large duckweed	Floating
TYPANG	*Typha angustifolia*	Narrow leafed cattail	Emergent
TYPGLA	*Typha glauca*	Hybrid cattail	Emergent
TYPLAT	*Typha latifolia*	Broad leafed cattail	Emergent
UTR SP	*Utricularia species*	Bladderwort species	Submergent
WOLCOL	*Wolffia columbiana*	Water meal	Floating

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					**DATE: 7/27/05**
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 01	Waterbody Name: Riddles Lake				Center of the Bed
Bed Size: 0.7 acre					Latitude: NA
Substrate: 1	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 40				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S:1	N:4	F:3	E:1	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
CERDEM	1			
LEMMIO	2			
NUPADV	2			
NYMTUB	2			
PELVIR	1			
SPIPOL	1			
WOLCOL	4			

Individual Plant Bed Survey

Comments: Plant bed 01 is contained entirely within the man-made Conservation Club channel. Watermeal (WOLCOL) is especially dense throughout the channel. Emergent plants are limited to narrow bands along the outside edges of the channel's shoreline.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					DATE: 7/27/05
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 02	Waterbody Name: Riddles Lake				Center of the Bed
Bed Size: 15.4 acres					Latitude: NA
Substrate: 3, 1	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 40				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S:3	N: 3	F:3	E:2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
BIDCER	1			
BOECYC	1			
CEPOCC	1			
CERDEM	3			
DECVER	1			
ELONUT	1			
FILALG	2			
IMPCAP	1			
LEEORY	1			
LEMMIO	2			
LEMTRI	1			
LYTSAL	2			
MYRSPI	1			
NAJGUA	1	1		
NUPADV	3			
NYMTUB	2			
PELVIR	1			
PHAARU	1			
POLCOC	1			
POLLAP	1			
POLPER	1			
PONCOR	1			

Individual Plant Bed Survey

Comments: Plant bed 02 covers a majority of Riddles Lake's shoreline. It extends from the Conservation Club channel northwest along the north shoreline and around along the southern shoreline to the Walters Ditch outlet. Reed canary grass and purple loosestrife are present in scattered clumps along the shoreline. Curly leaf pondweed and Eurasian water milfoil are also dense in scattered locations throughout the plant bed. Most other submerged species are sparse.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					DATE: 7/27/05
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 02	Waterbody Name: Riddles Lake				Center of the Bed
Bed Size: 15.4 acres					Latitude: NA
Substrate: 3, 1	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 40				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S:3	N: 3	F:3	E:2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
POTCRI	1			
POTFOL	2	1		
RUMSP	1			
SCIVAC	1			
SPIPOL	1			
TYPANG	1			
TYPGLA	2			
TYPLAT	2			
UTRSP	1			
WOLCOL	3			

Individual Plant Bed Survey

Comments:

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or
letter to denote specific
location of a species;
referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					DATE: 7/27/05
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 03	Waterbody Name: Riddles Lake				Center of the Bed
Bed Size: 1.4					Latitude: NA
Substrate: 3	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 40				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S:3	N:2	F:1	E:2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
CERDEM	2			
DECVER	1			
FILALG	2			
IMPCAP	1			
LEMMIO	1			
LYCAME	1			
LYTSAL	1			
MYRSPI	1			
NAJGUA	2	1		
NYMTUB	1			
PELVIR	1			
PILPUM	1			
POLLAP	1			
PONCOR	2			
SCIVAC	1			
SPIPOL	1			
TYPANG	2			
TYPGLA	1			
TYPLAT	1			
WOLCOL	2			

Individual Plant Bed Survey

Comments: Plant bed 03 covers most of the eastern shore of Riddles Lake. Leafy pondweed (POTFOL) is much denser in this plant bed than anywhere else in the lake. Much of this plant bed is adjacento residential areas where a sparse natural shoreline is currently present. Scatter clumps of purple loosestrife are present throught the plant bed.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew	**DATE: 7/27/05**

SITE INFORMATION					SITE COORDINATES
Plant Bed ID: 04	Waterbody Name: Riddles Lake				Center of the Bed
Bed Size: 11.8 acres					Latitude: NA
Substrate: 1	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 40				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S:3	N:2	F:3	E:2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
ALISUB	1			
BIDCER	1			
BOECYC	1			
CERDEM	3			
CICBUL	1	1		
DECVER	1			
ECHCRU	1			
ELEACI	1			
FILALG	2			
LEEORY	1			
LEMMIO	1			
LEMTRI	1			
LYTSAL	1			
MYRSPI	2			
NAJGUA	2	1		
NUPADV	3			
NYMTUB	2			
PELVIR	1			
PHAARU	1			
POLLAP	1			
PONCOR	2			
SAGLAT	1			

Individual Plant Bed Survey

Comments: Plant bed 04 covers the southern end of Riddles Lake. Spatterdock and coontail dominate this bed. Filamentous algae, Eurasian water milfoil, southern naiad, white water lily, cattail, and watermeal are also prevalent within this plant bed.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew	DATE: 7/27/05

SITE INFORMATION					SITE COORDINATES
Plant Bed ID: 04	Waterbody Name: Riddles Lake				Center of the Bed
Bed Size: 11.8 acres					Latitude: NA
Substrate: 1	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 40				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S:3	N:2	F:3	E:2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
SCIPUN	1			
SPAEUR	1			
SPIPOL	1			
TYPLAT	2			
WOLCOL	2			

Individual Plant Bed Survey

Comments:

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Reconnaissance Sampling

Waterbody Cover Sheet

Field	Value
Surveying Organization:	JFNew
Waterbody Name:	Pleasant Lake
Lake ID:	
County:	St. Joseph
Date:	7/27/05
Habitat Stratum:	IL
Ave. Lake Depth (ft):	17 ft
Lake Level:	
Crew Leader:	S. Peel
Recorder:	S. Namestnik

GPS Metadata

Datum:	Zone:	Accuracy:
NAD 83	16N	<1 m

Method: Trimble PRO XRS

Field	Value
Secchi Depth (ft):	1.7
Total # of Plant Beds Surveyed:	1
Total # of Species:	26

Littoral Zone Size (acres): 17.3 ac

- ❑ Measured
- ✓ Estimated

Littoral Zone Max. Depth (ft): 5.1 ft

- ❑ Measured
- ❑ Estimate (historical Secchi)
- ✓ Estimated (current Secchi)

Notable Conditions:

Abbreviation	Scientific Name	Common Name	Stratum
ACESAI	*Acer saccharium*	Silver maple	Emergent
BOECYL	*Boehmeria cylindrica*	False nettle	Emergent
CEPOCC	*Cephalanthus occidentalis*	Buttonbush	Emergent
CERDEM	*Ceratophyllum demersum*	Coontail	Submergent
CUSATA SP	*Cusata* species	Carrot family	Emergent
DECVER	*Decodon verticillatus*	Whirled loosestrife	Emergent
FILALG	*Filamentous algae*	Filamentous algae	Algae
IMPCAP	*Impatiens capensis*	Spotted touch-me-not	Emergent
LEEORY	*Leersia oryzoides*	Rice cut grass	Emergent
LEMMIO	*Lemna minor*	Common duckweed	Floating
LEMTRI	*Lemna trisulca*	Star duckweed	Floating
LYTSAL	*Lythrum salicaria*	Purple loosestrife	Emergent
MYRSPI	*Myriophyllum spicatum*	Eurasian water milfoil	Submergent
NAJGUA	*Najas guadalupensis*	Southern naiad	Submergent
NUPADV	*Nuphar advena*	Spatterdock	Floating
NYMTUB	*Nyphaea tuberosa*	White water lily	Floating
PELVIR	*Peltandra virginica*	Arrow arum	Emergent
PHAARU	*Phalarus arundinacaea*	Reed canary grass	Emergent
POLLAP	*Polygonum lapathifolia*	Nodding smartweed	Emergent
PONCOR	*Pontedaria cordata*	Pickerel weed	Emergent
POTCRI	*Potamogeton crispus*	Curly leaf pondweed	Submergent
POTFOL	*Potamogeton foliosis*	Narrow leaf pondweed	Submergent
SPIPOL	*Spirodela polyrhiza*	Large duckweed	Floating
TYPANG	*Typha angustifolia*	Narrow leafed cattail	Emergent
TYPLAT	*Typha latifolia*	Broad leafed cattail	Emergent
WOLCOL	*Wolffia columbiana*	Water meal	Floating

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew	**DATE: 7/27/05**

SITE INFORMATION					SITE COORDINATES
Plant Bed ID: 01	Waterbody Name: Pleasant Lake				Center of the Bed
Bed Size: 17.3 acres					Latitude: NA
Substrate: 1	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 26				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S: 3	N: 3	F: 3	E: 2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
ACESAI	1			
BOECYC	1			
CEPOCC	1			
CERDEM	3			
CUSSP	1			
DECVER	1			
FILALG	3			
IMPCAP	1			
LEEORY	1			
LEMMIO	2			
LEMTRI	1			
LYTSAL	1			
MYRSPI	2			
NAJGUA	1			
NUPADV	3			
NYMTUB	2			
PELVIR	2			
POLLAP	1			
PONCOR	2			
POTCRI	1			
POTFOL	1			
PHAARU	1			

Individual Plant Bed Survey

Comments: Plant bed 01 rings the entire shoreline of Pleasant Lake. Eurasian water milfoil is dense throughout the lake. Purple loosestrife is dense in scattered locations around the lake, especially adjacent to the boat ramp. Reed canary grass and curly leaf pondweed are also scattered along the shoreline and throughout the plant bed.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew					**DATE: 7/27/05**
SITE INFORMATION					**SITE COORDINATES**
Plant Bed ID: 01	Waterbody Name: Pleasant Lake				Center of the Bed
Bed Size: 17.3 acres					Latitude: NA
Substrate: 1	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 26				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S: 3	N: 3	F: 3	E: 2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
SPIPOL	1			
TYPANG	1			
TYPLAT	2			
WOLCOL	3			

Individual Plant Bed Survey

Comments:

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

Abbreviation	**Scientific Name**	**Common Name**	**Stratum**
BOECYC	*Boehmeria cylindrica*	False nettle	Emergent
CALCAN	*Calamograostis canadensis*	Blue joint grass	Submergent
CEPOCC	*Cephalanthus occidentalis*	Buttonbush	Emergent
CERDEM	*Ceratophyllum demersum*	Coontail	Submergent
CHARA	*Chara species*	Chara species	Submergent
DECVER	*Decodon verticillatus*	Whirled loosestrife	Emergent
LEMMIO	*Lemna minor*	Common duckweed	Floating
LEMTRI	*Lemna trisulca*	Star duckweed	Floating
LYTSAL	*Lythrum salicaria*	Purple loosestrife	Emergent
NAJGUA*	*Najas guadalupensis*	Southern naiad	Submergent
NUPADV	*Nuphar advena*	Spatterdock	Floating
NYMTUB	*Nyphaea tuberosa*	White water lily	Floating
PELVIR	*Peltandra virginica*	Arrow arum	Emergent
PHAARU	*Phalarus arundinacaea*	Reed canary grass	Emergent
POLFOL*	*Potamogeton foliosis*	Narrow leaf pondweed	Submergent
PONCOR	*Pontedaria cordata*	Pickerel weed	Emergent
POTCRI	*Potamogeton crispus*	Curly leaf pondweed	Submergent
SAMCAN	*Sambucus canadensis*	Elderberry	Emergent
SOLDUL	*Solanum dulcomera*	Climbing nightshade	Emergent
SPIPOL	*Spirodela polyrhiza*	Large duckweed	Floating
TYPLAT	*Typha latifolia*	Broad leafed cattail	Emergent
WOLCOL	*Wolffia columbiana*	Water meal	Floating

Aquatic Vegetation Plant Bed Data Sheet

State of Indiana Department of Natural Resources

ORGANIZATION: JFNew

DATE: 7/27/05

SITE INFORMATION					SITE COORDINATES
Plant Bed ID: Channel	Waterbody Name: Heston Ditch (channel connecting Pleasant and Riddles lakes)				Center of the Bed
Bed Size: 3.6					Latitude: NA
Substrate: 1	Waterbody ID:				Longitude: NA
Marl?	Total # of Species: 22				Max. Lakeward Extent of Bed
High Organic?	**CanopyAbundance at Site**				Latitude: NA
	S:3	N:2	F:3	E:2	Longitude: NA

SPECIES INFORMATION

Species Code	Abundance	QE	Vchr.	Ref. ID
BOECYC	1			
CALCAN	1			
CEPOCC	1			
CERDEM	3			
CHAVUL	1			
DECVER	1			
LEMMIO	1			
LEMTRI	1			
LYTSAL	1			
NAJGUA	1			
NUPADV	3			
NYMTUB	2			
PELVIR	1			
PHAARU	1			
PONCOR	1			
POTCRI	1			
POTFOL	1	1		
SAMCAN	1			
SOLDUL	1			
SPIPOL	1			
TYPLAT	1			
WOLCOL	3			

Individual Plant Bed Survey

Comments: This plant bed extends from the outlet of Pleasant Lake along the length of Heston Ditch to the inlet of Riddles Lake. Most of the shoreline is vegetated with dense emergent and rooted floating plants. The centerline of the channel contains a majority of submerged plant species and is dominated by coontail.

REMINDER INFORMATION

Substrate:
1 = Silt/Clay
2 = Silt w/Sand
3 = Sand w/Silt
4 = Hard Clay
5 = Gravel/Rock
6 = Sand

Marl
1 = Present
0 = absent

High Organic
1 = Present
0 = absent

Overall Surface Cover
N = Nonrooted floating
F = Floating, rooted
E = Emergent
S = Submersed

Canopy:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

Abundance:
1 = < 2%
2 = 2-20%
3 = 21-60%
4 = > 60%

QE Code:
0 = as defined
1 = Species suspe
2 = Genus suspected
3 = Unknown

Voucher:
0 = Not Taken
1 = Taken, not varified
2 = Taken, varifie

Reference ID:
Unique number or letter to denote specific location of a species; referenced on attached map

APPENDIX I:

PLANT SPECIES FOUND IN PLEASANT AND RIDDLES LAKES BY THE INDIANA DEPARTMENT OF NATURAL RESOURCES DIVISION OF FISH AND WILDLIFE

PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY

ST. JOSEPH COUNTY, INDIANA

Table 1. Macrophyte community present in Riddles Lake during Indiana Department of Natural Resources fisheries surveys.

Common Name	Scientific Name	1964	1974	1985	1987	2003
Arrowhead	*Sagittaria latifolia*	X		X	X	
Cattail	*Typha latifolia*	X	X	X	X	X
Common waterweed	*Elodea canadensis*					X
Coontain	*Ceratophyllum demersum*	X	X			X
Curly-leaf pondweed	*Potamogeton crispus*	X	X			
Duckweed	*Lemna minor*			X	X	
Eurasian water milfoil	*Myriophyllum spicatum*					X
Filamentous algae			X	X	X	
Leafy/fine leafted pondweed	*Potamogeton foliosis*	X				X
Milfoil	*Myriophyllum species*			X	X	
Pickerelweed	*Pontederia cordata*	X	X			X
Purple loosestrife	*Lythrum salicaria*			X	X	
River bulrush	*Scirpus fluviatilis*	X				
Sago pondweed	*Potamogeton pectinatus*	X				
Spatterdock	*Nuphar advena*	X	X	X	X	X
Swamp loosestrife	*Decodon verticillatus*	X				
Watermeal	*Wolffia species*					X
Water willow	*Justicia american*		X			
White water lily	*Nympaea tuberosa*	X	X			X
Total Number of Species		**11**	**8**	**7**	**7**	**9**

Table 2. Macrophyte community present in Pleasant Lake during Indiana Department of Natural Resources fisheries surveys.

Common Name	Scientific Name	1977	1978	1986	2003
Arrow arum	Peltandra virginica				X
Arrowhead	*Sagittaria latifolia*	X	X		
Cattail	*Typha latifolia*			X	
Coontail	*Ceratophyllum demersum*	X	X	X	X
Curly-leaf pondweed	*Potamogeton crispus*	X	X		
Duckweed	*Lemna minor*	X	X	X	X
Eurasian water milfoil	*Myriophyllum spicatum*		X		X
Humped bladderwort	*Utricularia gibba*				X
Leafy/fine leafted pondweed	*Potamogeton foliosis*				X
Milfoil	*Myriophyllum species*	X		X	
Pickerelweed	*Pontederia cordata*				X
Purple loosestrife	*Lythrum salicaria*			X	
Spatterdock	*Nuphar advena*			X	X
Watermeal	*Wolffia species*				X
Swamp loosestrife	*Decodon verticillatus*	X			
White water lily	*Nympaea tuberosa*	X	X	X	X
Water willow	*Justicia americana*		X		
Total Number of Species		**7**	**7**	**7**	**10**

APPENDIX J:

FISH SPECIES IDENTIFIED IN PLEASANT AND RIDDLES LAKES BY THE INDIANA DEPARTMENT OF NATURAL RESOURCES DIVISION OF FISH AND WILDLIFE

PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY

ST. JOSEPH COUNTY, INDIANA

Table 1. Fish species identified in Riddles Lake by the Indiana Department of Natural Resources, Division of Fish and Wildlife Fisheries Biologists.

Common Name	Scientific Name	1964	1974	1976	1985	1987	2003
Sunfish Family							
Bluegill	*Lepomis macrochirus*	X	X	X	X	X	X
Black Crappie	*Pomoxis nigromaculatus*	X	X	X	X	X	X
Green Sunfish	*Lepomis cyanellus*	X			X		
Largemouth Bass	*Micropterus salmoides*	X	X	X	X	X	X
Pumpkinseed	*Lepomis gibbosus*	X	X	X	X	X	X
Redear Sunfish	*Lepomis microlophus*						X
Warmouth	*Lepomis gulosus*	X	X		X	X	X
White Crappie	*Pomoxis annularis*	X			X	X	X
Catfish Family							
Black Bullhead	*Ameiurus melas*		X		X	X	
Brown Bullhead	*Ameiurus nebulosus*	X	X	X	X	X	X
Channel Catfish	*Ictalurus punctatus*				X		
Yellow Bullhead	*Ameiurus natalis*	X	X	X		X	X
Minnow Family							
Common Carp	*Cyprinus carpio*	X	X				
Common Shiner	*Luxilus cornutus*	X					
Golden Shiner	*Notemigonus crysoleucas*	X	X	X	X	X	
Sucker Family							
Bigmouth Buffalo	*Ictiobus cyprinellus*	X			X	X	
Spotted Sucker	*Minytrema melanops*	X	X	X			
White Sucker	*Catostomus commersoni*	X	X	X	X	X	X
Bowfin Family							
Bowfin	*Amia calva*		X			X	X
Herring Family							
Gizzard Shad	*Dorosoma cepedianum*	X	X	X	X	X	X
Gar Family							
Spotted Gar	*Lepisosteus oculatus*			X	X	X	X
Pike Family							
Grass Pickerel	*Esox americanus vermiculatus*				X	X	
Perch Family							
Walleye	*Stizostedion vitreum vitreum*						X
Yellow Perch	*Perca flavescens*	X	X	X	X	X	X
Number Species		**17**	**15**	**12**	**17**	**17**	**15**

Table 2. Fish species identified in Pleasant Lake by the Indiana Department of Natural Resources, Division of Fish and Wildlife Fisheries Biologists.

Common Name	Scientific Name	1972	1977	1978	1986	2003
Sunfish Family						
Bluegill	*Lepomis macrochirus*	X	X	X	X	X
Black Crappie	*Pomoxis nigromaculatus*	X	X	X	X	
Largemouth Bass	*Micropterus salmoides*	X	X	X	X	X
Pumpkinseed	*Lepomis gibbosus*	X	X	X	X	X
Redear Sunfish	*Lepomis microlophus*					X
Warmouth	*Lepomis gulosus*		X	X	X	X
White Crappie	*Pomoxis annularis*			X	X	X
Catfish Family						
Black Bullhead	*Ameiurus melas*		X		X	
Brown Bullhead	*Ameiurus nebulosus*			X	X	
Channel Catfish	*Ictalurus punctatus*				X	
Yellow Bullhead	*Ameiurus natalis*		X		X	X
Minnow Family						
Common Carp	*Cyprinus carpio*	X		X	X	
Golden Shiner	*Notemigonus crysoleucas*	X	X	X	X	
Sucker Family						
Spotted Sucker	*Minytrema melanops*				X	X
White Sucker	*Catostomus commersoni*	X	X	X	X	
Bowfin Family						
Bowfin	*Amia calva*		X	X	X	X
Herring Family						
Gizzard Shad	*Dorosoma cepedianum*	X	X		X	X
Gar Family						
Shortnose Gar	*Lepisosteus platostomus*		X			
Spotted Gar	*Lepisosteus oculatus*		X		X	X
Pike Family						
Grass Pickerel	*Esox americanus vermiculatus*		X		X	
Northern Pike	*Esox lucius*		X	X	X	
Perch Family						
Yellow Perch	*Perca flavescens*			X		
Silverside Family						
Brook Silverside	*Labidesthes sicculus*		X			
Number Species		**8**	**16**	**13**	**19**	**11**

APPENDIX K:

WATER BUDGET CALCULATIONS

PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY

ST. JOSEPH COUNTY, INDIANA

Table 1. Water budget calculations for Riddles Lake.

Watershed	Riddles Lake
Watershed size (ac)	2,128
Mean Watershed Runoff (ac-ft/yr)	2,202
Lake Volume (ac-ft)	624
Closest gauged stream	Yellow River at Plymouth
Stream watershed (mi^2)	294
Stream watershed (acres)	188,160
Mean annual Q (cfs)	269
Mean annual Q (ac-ft/yr)	194,747
Mean ppt (in/yr)	36.8
Mean watershed ppt (ac-ft/yr)	576,710
Watershed C	0.34
Pan evaporation (in/yr)	28.05
Pan evaporation coefficient	0.70
Lake Surface Area (acres)	76
Estimated lake evaporation (ac-ft)	125
Direct precipitation to lake (ac-ft)	234
Water Budget Summary	
Direct precipitation to lake (ac-ft)	234
Runoff from immediate watershed (ac-ft)	2,202
Discharge from Pleasant Lake (ac-ft)	5,855
Evaporation (ac-ft)	125
TOTAL LAKE OUTPUT (ac-ft)	8,166
Hydraulic Residence Time (yr)	0.08
Watershed Area:Lake Area	99:1

Table 2. Water budget calculations for Pleasant Lake.

Watershed	Pleasant Lake
Watershed size (ac)	4,446
Mean Watershed Runoff (ac-ft/yr)	4,602
Lake Volume (ac-ft)	663
Closest gauged stream	Yellow River at Plymouth
Stream watershed (mi^2)	294
Stream watershed (acres)	188,160
Mean annual daily Q (cfs)	269
Mean annual Q (ac-ft/yr)	194,747
Mean ppt (in/yr)	36.78
Mean watershed ppt (ac-ft/yr)	576,710
Watershed C	0.34
Pan evaporation (in/yr)	28.05
Pan evaporation coefficient	0.70
Lake Surface Area (acres)	29
Estimated lake evaporation (ac-ft)	47
Direct precipitation to lake (ac-ft)	89
Water Budget Summary	
Direct precipitation to lake (ac-ft)	89
Runoff from watershed (ac-ft)	4,602
Discharge from Fites Lake (ac-ft)	1,212
Evaporation (ac-ft)	47
TOTAL LAKE OUTPUT (ac-ft)	5,855
Hydraulic Residence Time (yr)	0.11
Watershed Area:Lake Area	192:1

Table 3. Water budget calculations for Fites Lake.

Watershed	**Fites Lake**
Watershed size (ac)	1,157
Mean Watershed Runoff (ac-ft/yr)	1,198
Lake Volume (ac-ft)	unknown
Closest gaged stream	Yellow River at Plymouth
Stream watershed (mi^2)	294
Stream watershed (acres)	188,160
Mean annual Q (cfs)	269
Mean annual Q (ac-ft/yr)	194,747
Mean ppt (in/yr)	36.8
Mean watershed ppt (ac-ft/yr)	576,710
Watershed C	0.34
Pan evaporation (in/yr)	28.05
Pan evaporation coefficient	0.70
Lake Surface Area (acres)	10
Estimated lake evaporation (ac-ft)	16
Direct precipitation to lake (ac-ft)	31
Water Budget Summary	
Direct precipitation to lake (ac-ft)	31
Runoff from watershed (ac-ft)	1,198
Evaporation (ac-ft)	16
TOTAL LAKE OUTPUT (ac-ft)	1,212
Hydraulic Residence Time (yr)	-
Watershed Area:Lake Area	115.7:1

APPENDIX L:

PHOSPHORUS MODEL CALCULATIONS

PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY

ST. JOSEPH COUNTY, INDIANA

Table 1. Phosphorus Model for Riddles Lake.

Phosphorus Loading - Lake Response Model				
INPUT DATA		**Unit**		
Area, Lake	76	acres		
Volume, Lake	624	ac-ft		
Mean Depth	8.2	ft		
Hydraulic Residence Time	0.08			
Flushing Rate	12.50	1/yr		
Mean Annual Precipitation	0.90	m		
[P] in precipitation	0.03	mg/l		
[P] in epilimnion	0.113	mg/l		
[P] in hypolimnion	0.996	mg/l		
Volume of epilimnion	511	ac-ft		
Volume of hypolimnion	114	ac-ft		
Land Use (in watershed)	**Area**		**P-export Coefficient**	
Deciduous Forest	112.8	hectare	0.20	kg/ha-yr
Emergent Herbaceous Wetlands	14.1	hectare	0.10	kg/ha-yr
Evergreen Forest	0.6	hectare	0.15	kg/ha-yr
High Intensity Residential	0.1	hectare	1.50	kg/ha-yr
High Intensity:Commercial/Ind	11.5	hectare	1.30	kg/ha-yr
Low Intensity Residential	46.2	hectare	0.60	kg/ha-yr
Mixed Forest	0.3	hectare	0.18	kg/ha-yr
Pasture/Hay	124.2	hectare	0.60	kg/ha-yr
Row Crops	516.2	hectare	1.50	kg/ha-yr
Woody Wetlands	11.0	hectare	0.10	kg/ha-yr
Septic Systems			0.50	kg/ha-yr
Other Data				
Soil Retention coefficient	0.75			
# Permanent Homes	6	homes		
Use of Permanent Homes	1.0	year		
# Seasonal Homes	0	homes		
Use of Seasonal Homes	0.25	year		
# Seasonal Homes	0	homes		
Use of Seasonal Homes	0.09	year		
Avg. Persons Per Home	3	persons		
OUTPUT				
P load from watershed	916.8	kg/yr		
P load from Pleasant Lake	2174.0	kg/yr		
P load from precipitation	8.32	kg/yr		
P load from septic systems	2.25	kg/yr		
Total External P load	3101.33	kg/yr		
Areal P loading	10.083	g/m^2-yr		
Predicted P from Vollenweider	0.244	mg/l		
Back Calculated L total	11.302	g/m^2-yr		
Estimation of L internal	1.218	g/m^2-yr		
% of External Loading	89.2	%		
% of Internal Loading	10.8	%		

Table 2. Phosphorus Model for Pleasant Lake.

Phosphorus Loading - Lake Response Model				
INPUT DATA		**Unit**		
Area, Lake	29	acres		
Volume, Lake	663	ac-ft		
Mean Depth	22.9	ft		
Hydraulic Residence Time	0.11			
Flushing Rate	9.09	1/yr		
Mean Annual Precipitation	0.90	m		
[P] in precipitation	0.03	mg/l		
[P] in epilimnion	0.094	mg/l		
[P] in hypolimnion	0.714	mg/l		
Volume of epilimnion	442	ac-ft		
Volume of hypolimnion	221	ac-ft		
Land Use (in watershed)	**Area**		**P-export Coefficient**	
Row Crops	1136.3	hectare	1.50	kg/ha-yr
Pasture/Hay	361.6	hectare	0.60	kg/ha-yr
Deciduous Forest	334.7	hectare	0.20	kg/ha-yr
Low Intensity Residential	153.9	hectare	0.60	kg/ha-yr
Woody Wetlands	131.3	hectare	0.10	kg/ha-yr
High Intensity:Commercial/Ind/Trans	57.9	hectare	1.30	kg/ha-yr
Emergent Herbaceous Wetlands	35.3	hectare	0.10	kg/ha-yr
High Intensity Residential	15.4	hectare	1.50	kg/ha-yr
Other Grasses	13.2	hectare	0.50	kg/ha-yr
Evergreen Forest	2.0	hectare	0.15	kg/ha-yr
Mixed Forest	0.1	hectare	0.18	kg/ha-yr
Septic Systems			0.50	kg/ha-yr
Other Data				
Soil Retention coefficient	0.75			
# Permanent Homes	2	homes		
Use of Permanent Homes	1.0	year		
# Seasonal Homes	0	homes		
Use of Seasonal Homes	0.25	year		
# Seasonal Homes	0	homes		
Use of Seasonal Homes	0.09	year		
Avg. Persons Per Home	3	persons		
OUTPUT				
P load from watershed	2202.58	kg/yr		
P load from precipitation	3.18	kg/yr		
P load from septic systems	0.75	kg/yr		
Total External P load	2206.51	kg/yr		
Areal P loading	18.801	g/m^2-yr		
Predicted P from Vollenweider	0.256	mg/l		
Back Calculated L total	22.054	g/m^2-yr		
Estimation of L internal	3.253	g/m^2-yr		
% of External Loading	85.3	%		
% of Internal Loading	14.7	%		

Table 1. Potential shoreline buffer species.

Common Name	**Botanical Name**	**Approximate Location***
Arrow Arum	*Peltandra virginica*	Shallow water/water's edge
Big Blue Stem	*Andropogon gerardii*	Varies/broad range
Black-Eyed Susan	*Rudbeckia hirta*	Drier soils
Blue Flag Iris	*Iris virginica shrevei*	Shallow water/water's edge
Blue Joint Grass	*Calamagrostis canadensis*	Wet to mesic soils
Bottle Gentian	*Gentiana andrewsii*	Mesic to dry soils
Butterfly Milkweed	*Asclepias tuberosa*	Mesic to dry soils
Chairmakers rush	*Scirpus pungens*	Shallow water/water's edge
Common Bur Reed	*Sparganium eurycarpum*	Shallow water/water's edge
Compass Plant	*Silphium laciniatum*	Varies/broad range
Cream Wild Indigo	*Baptisia leucophaea*	Mesic to dry soils
Culver's Root	*Veronicastrum virginianum*	Varies/broad range
Cup Plant	*Silphium perfoliatum*	Wet to mesic soils
Early Goldenrod	*Solidago juncea*	Wet to mesic soils
False Dragonhead	*Physostegia virginiana*	Wet to mesic soils
Goats Rue	*Tephrosia virginiana*	Varies/broad range
Golden Alexanders	*Zizia aurea*	Wet to mesic soils
Great Blue Lobelia	*Lobelia siphilitica*	Wet soils
Halberd-leaved Rose Mallow	*Hibiscus laevis*	Shallow water/water's edge
Hard-stemmed Bulrush	*Scirpus acutus*	Shallow water/water's edge
Heart-Leaved Meadow Parsnip	*Zizia aptera*	Mesic to dry soils
Heath Aster	*Aster ericoides*	Wet to mesic soils
Illinois Sensitive Plant	*Desmanthus illinoensis*	Mesic to dry soils
Illinois Tick Trefoil	*Desmodium illinoiense*	Varies/broad range
Indian Grass	*Sorghastrum nutans*	Varies/broad range
Ironweed	*Vernonia altissima*	Wet to mesic soils
Little Blue Stem	*Andropogon scoparius*	Varies/broad range
Marsh Blazing Star	*Liatris spicata*	Wet to mesic soils
New England Aster	*Aster novae-angliae*	Wet to mesic soils
New Jersey Tea	*Ceanothus americanus*	Varies/broad range
Old-Field Goldenrod	*Solidago nemoralis*	Mesic to dry soils
Partridge Pea	*Cassia fasciculata*	Varies/broad range
Pickerel Weed	*Pontederia cordata*	Shallow water/water's edge
Prairie Bergamot	*Monarda fistulosa*	Varies/broad range
Prairie Cinquefoil	*Potentilla arguta*	Mesic to dry soils
Prairie Cord Grass	*Spartina pectinata*	Wet to mesic soils
Prairie Coreopsis	*Coreopsis palmata*	Mesic to dry soils
Prairie Dock	*Silphium terebinthinaceum*	Varies/broad range
Prairie Switch Grass	*Panicum virgatum*	Varies/broad range
Prairie Wild Rye	*Elymus canadensis*	Varies/broad range
Purple Coneflower	*Echinacea purpurea*	Mesic to dry soils
Rattlesnake Master	*Eryngium yuccifolium*	Varies/broad range
Rosin Weed	*Silphium integrifolium*	Varies/broad range

Common Name	**Botanical Name**	**Approximate Location***
Rough Blazing Star	*Liatris aspera*	Mesic to dry soils
Round-Head Bush Clover	*Lespedeza capitata*	Varies/broad range
Rushes	*Juncus* spp.	Depends upon the species
Saw-Tooth Sunflower	*Helianthus grosseserratus*	Wet to mesic soils
Sedges	*Carex* spp.	Depends upon the species
Showy Goldenrod	*Solidago speciosa*	Mesic to dry soils
Side Oats Grama	*Bouteloua curtipendula*	Mesic to dry soils
Sky-Blue Aster	*Aster azureus*	Mesic to dry soils
Smooth Aster	*Aster laevis*	Mesic to dry soils
Sneezeweed	*Helenium autumnale*	Wet to mesic soils
Softsem Bulrush	*Scirpus validus creber*	Shallow water/water's edge
Spider-Wort	*Tradescantia ohiensis*	Wet to mesic soils
Stiff Goldenrod	*Solidago rigida*	Varies/broad range
Swamp Loosestrife	*Decodon verticillatus*	Shallow water/water's edge
Swamp Rose Mallow	*Hibiscus palustris*	Shallow water/water's edge
Sweet Black-Eyed Susan	*Rudbeckia subtomentosa*	Wet to mesic soils
Sweet Flag	*Acorus calamus*	Shallow water/water's edge
Tall Coreopsis	*Coreopsis tripteris*	Wet to mesic soils
Thimbleweed	*Anemone cylindrica*	Mesic to dry soils
Virginia Mountain Mint	*Pycnanthemum virginianum*	Varies/broad range
White Wild Indigo	*Baptisia leucantha*	Varies/broad range
Wild Lupine	*Lupinus perennis*	Mesic to dry soils
Wild Quinine	*Parthenium integrifolium*	Varies/broad range
Wrinkled Goldenrod	*Solidago rugosa*	Wet to mesic soils
Yellow Coneflower	*Ratibida pinnata*	Varies/broad range

** These approximate locations are very general. Each species can have specific site conditions requirements (i.e. sun exposure, soil type, soil moisture). Consequently, site inspection should occur before determining an exact species list for a given site.*

APPENDIX N:

POTENTIAL FUNDING SOURCES

PLEASANT AND RIDDLES LAKES WATERSHED DIAGNOSTIC STUDY

ST. JOSEPH COUNTY, INDIANA

POTENTIAL FUNDING SOURCES

There are several cost-share grants available from both state and federal government agencies specific to watershed management. Community groups and/or Soil and Water Conservation Districts can apply for the majority of these grants. The main goal of these grants and other funding sources is to improve water quality though the use of specific BMPs. As public awareness shifts towards watershed management, these grants will become more and more competitive. Therefore, any association interested in improving water quality through the use of grants must become active soon. Once an association is recognized as a "watershed management activist" it will become easier to obtain these funds repeatedly. The following are some of the possible major funding sources available to lake and watershed associations for watershed management.

Lake and River Enhancement Program (LARE)
LARE is administered by the Indiana Department of Natural Resources, Division of Fish and Wildlife. The program's main goals are to control sediment and nutrient inputs to lakes and streams and prevent or reverse degradation from these inputs through the implementation of corrective measures. Under present policy, the LARE program may fund lake and watershed specific construction actions up to $100,000 for a single project or $300,000 for all projects on a lake or stream. The LARE program also provides a maximum of $100,000 for the removal of sediment from a particular site on a lake and a cumulative total of $300,000 for all sediment removal projects on a lake. An approved sediment removal plan must be on file with the LARE office for projects to receive sediment removal funding. Finally, the LARE program will provide $100,000 for a one-time whole lake treatment to control aggressive, invasive aquatic plants. A cumulative total of $20,000 over a three year period may be obtained for additional spot treatment following the whole lake treatment. As with the sediment removal funding, an approved aquatic plant management plan must be on file with the LARE office for the lake association to receive funding. All approved projects require a 0 to 25% cash or in-kind match, depending on the project. LARE also has a "watershed land treatment" component that can provide grants to SWCDs for multi-year projects. The funds are available on a cost-sharing basis with landowners who implement various BMPs. All of the LARE programs are recommended as a project funding source for the Blue Lake watershed. More information about the LARE program can be found at http://www.in.gov/dnr/fishwild/lare/.

Clean Water Act Section 319 Nonpoint Source Pollution Management Grant
The 319 Grant Program is administered by the Indiana Department of Environmental Management (IDEM), Office of Water Management, Watershed Management Section. 319 is a federal grant made available by the Environmental Protection Agency (EPA). 319 grants fund projects that target nonpoint source water pollution. Nonpoint source pollution (NPS) refers to pollution originating from general sources rather than specific discharge points (Olem and Flock, 1990). Sediment, animal and human waste, nutrients, pesticides, and other chemicals resulting from land use activities such as mining, farming, logging, construction, and septic fields are considered NPS pollution. According to the EPA, NPS pollution is the number one contributor to water pollution in the United States. To qualify for funding, the water body must meet specific criteria such as being listed in the state's 305(b) report as a high priority water body or be identified by a diagnostic study as being impacted by NPS pollution. Funds can be requested for up to $300,000 for individual projects. There is a 25% cash or in-kind match requirement. To qualify for implementation projects, there must be a watershed management plan for the receiving waterbody. This plan must meet all of the current 319 requirements. This diagnostic study serves as an excellent foundation for developing a

watershed management plan since it satisfies several, but not all, of the 319 requirements for a watershed management plan. More information about the Section 319 program can be obtained from http://www.in.gov/idem/water/planbr/wsm/319main.html.

Section 104(b)(3) NPDES Related State Program Grants

Section 104(b)(3) of the Clean Water Act gives authority to a grant program called the National Pollutant Discharge Elimination System (NPDES) Related State Program Grants. These grants provide money for developing, implementing, and demonstrating new concepts or requirements that will improve the effectiveness of the NPDES permit program that regulates point source discharges of water pollution. Projects that qualify for Section 104(b)(3) grants involve water pollution sources and activities regulated by the NPDES program. The awarded amount can vary by project and there is a required 5% match. For more information on Section 104(b)(3) grants, please see the IDEM website at: http://www.in.gov/idem/water/planbr/wsm/104main.html.

Section 205(j) Water Quality Management Planning Grants

Funds allocated by Section 205(j) of the Clean Water Act are granted for water quality management planning and design. Grants are given to municipal governments, county governments, regional planning commissions, and other public organizations for researching point and non-point source pollution problems and developing plans to deal with the problems. According to the IDEM Office of Water Quality website: "The Section 205(j) program provides for projects that gather and map information on non-point and point source water pollution, develop recommendations for increasing the involvement of environmental and civic organizations in watershed planning and implementation activities, and implement watershed management plans. No match is required. For more information on and 205(j) grants, please see the IDEM website at: http://www.in.gov/idem/water/planbr/wsm/205jmain.html.

Other Federal Grant Programs

The USDA and EPA award research and project initiation grants through the U.S. National Research Initiative Competitive Grants Program and the Agriculture in Concert with the Environment Program.

Watershed Protection and Flood Prevention Program

The Watershed Protection and Flood Prevention Program is funded by the U.S. Department of Agriculture and is administered by the Natural Resources Conservation Service. Funding targets a variety of watershed activities including watershed protection, flood prevention, erosion and sediment control, water supply, water quality, fish and wildlife habitat enhancement, wetlands creation and restoration, and public recreation in small watersheds (250,000 or fewer acres). The program covers 100% of flood prevention construction costs or 50% of construction costs for agricultural water management, recreational, or fish and wildlife projects.

Conservation Reserve Program
The Conservation Reserve Program (CRP) is funded by the USDA and administered by the Farm Service Agency (FSA). CRP is a voluntary, competitive program designed to encourage farmers to establish vegetation on their property in an effort to decrease erosion, improve water quality, or enhance wildlife habitat. The program targets farmed areas that have a high potential for degrading water quality under traditional agricultural practices or areas that might make good wildlife habitat if they were not farmed. Such areas include highly erodible land, riparian zones, and farmed wetlands. Currently, the program offers continuous sign-up for practices like grassed waterways and filter strips. Participants in the program receive cost share assistance for any plantings or construction as well as annual payments for any land set aside.

Wetlands Reserve Program
The Wetlands Reserve Program (WRP) is funded by the USDA and is administered by the NRCS. WRP is a subsection of the Conservation Reserve Program. This voluntary program provides funding for the restoration of wetlands on agricultural land. To qualify for the program, land must be restorable and suitable for wildlife benefits. This includes farmed wetlands, prior converted cropland, farmed wet pasture, farmland that has become a wetland as a result of flooding, riparian areas which link protected wetlands, and the land adjacent to protected wetlands that contribute to wetland functions and values. Landowners may place permanent or 30-year easements on land in the program. Landowners receive payment for these easement agreements. Restoration cost-share funds are also available. No match is required.

Grassland Reserve Program
The Grassland Reserve Program (GRP) is funded by the USDA and is administered by the NRCS. GRP is a voluntary program that provides funding the restoration or improvement of natural grasslands, rangelands, prairies or pastures. To qualify for the program the land must consist of at least a 40 acre contiguous tract of land, be restorable, and provide water quality or wildlife benefit. Landowners may enroll land in the Grassland Reserve Program for 10, 15, 20, or 30 years or enter their land into a 30-year permanent easement. Landowners receive payment of up to 75% of the annual grazing value. Restoration cost-share funds of up to 75% for restored or 90% for virgin grasslands are also available.

Community Forestry Grant Program
The U.S. Forest Service through the Indiana Department of Natural Resources Division of Forestry provides three forms of funding for communities under the Community Forestry Grant Program. Urban Forest Conservation Grants (UFCG) are designed to help communities develop long term programs to manage their urban forests. UFCG funds are provided to communities to improve and protect trees and other natural resources; projects that target program development, planning, and education are emphasized. Local municipalities, not-for-profit organizations, and state agencies can apply for $2,000-20,000 annually. The second type of Community Forestry Grant Program, the Arbor Day Grant Program, funds activities which promote Arbor Day efforts and the planting and care of urban trees. $500-1000 grants are generally awarded. The Tree Steward Program is an educational training program that involves six training sessions of three hours each. The program can be offered in any county in Indiana and covers a variety of tree care and planting topics. Generally, $500-1000 is available to assist communities in starting a county or regional Tree Steward Program. Each of these grants requires an equal match.

Forest Land Enhancement Program (FLEP)
FLEP replaces the former Forestry Incentive Program. It provides financial, technical, and educational assistance to the Indiana Department of Natural Resources Division of Forestry to assist private landowners in forestry management. Projects are designed to enhance timber production, fish and wildlife habitat, soil and water quality, wetland and recreational resources, and aesthetic value. FLEP projects include implementation of practices to protect and restore forest lands, control invasive species, and preserve aesthetic quality. Projects may also include reforestation, afforestation, or agroforestry practices. The IDNR Division of Forestry has not determined how they will implement this program; however, their website indicates that they are working to determine their implementation and funding procedures. More information can be found at http://www.in.gov/dnr/forestry.

Wildlife Habitat Incentive Program
The Wildlife Habitat Incentive Program (WHIP) is funded by the USDA and administered by the NRCS. This program provides support to landowners to develop and improve wildlife habitat on private lands. Support includes technical assistance as well cost sharing payments. Those lands already enrolled in WRP are not eligible for WHIP. The match is 25%.

Environmental Quality Incentives Program
The Environmental Quality Incentives Program (EQIP) is a voluntary program designed to provide assistance to producers to establish conservation practices in target areas where significant natural resource concerns exist. Eligible land includes cropland, rangeland, pasture, and forestland, and preference is given to applications which propose BMP installation that benefits wildlife. EQIP offers cost-share and technical assistance on tracts that are not eligible for continuous CRP enrollment. Certain BMPs receive up to 75% cost-share. In return, the producer agrees to withhold the land from production for five years. Practices that typically benefit wildlife include: grassed waterways, grass filter strips, conservation cover, tree planting, pasture and hay planting, and field borders. Best fertilizer and pesticide management practices, innovative approaches to enhance environmental investments like carbon sequestration or market-based credit trading, and groundwater and surface water conservation are also eligible for EQIP cost-share.

Small Watershed Rehabilitation Program
The Small Watershed Rehabilitation Program provides funding for rehabilitation of aging small watershed impoundments that have been constructed within the last 50 years. This program is newly funded through the 2002 Farm Bill and is currently under development. More information regarding this and other Farm Bill programs can be found at http://www.usda.gov/farmbill.

Farmland Protection Program
The Farmland Protection Program (FPP) provides funds to help purchase development rights in order to keep productive farmland in use. The goals of FPP are: to protect valuable, prime farmland from unruly urbanization and development; to preserve farmland for future generations; to support a way of life for rural communities; and to protect farmland for long-term food security.

Debt for Nature
Debt for Nature is a voluntary program that allows certain FSA borrowers to enter into 10-year, 30-year, or 50-year contracts to cancel a portion of their FSA debts in exchange for devoting eligible acreage to conservation, recreation, or wildlife practices. Eligible acreage includes: wetlands, highly erodible lands, streams and their riparian areas, endangered species or significant wildlife habitat,

land in 100-year floodplains, areas of high water quality or scenic value, aquifer recharge zones, areas containing soil not suited for cultivation, and areas adjacent to or within administered conservation areas.

Partners for Fish and Wildlife Program

The Partners for Fish and Wildlife Program (PFWP) is funded and administered by the U.S. Department of the Interior through the U.S. Fish and Wildlife Service. The program provides technical and financial assistance to landowners interested in improving native habitat for fish and wildlife on their land. The program focuses on restoring wetlands, native grasslands, streams, riparian areas, and other habitats to natural conditions. The program requires a 10-year cooperative agreement and a 1:1 match.

North American Wetland Conservation Act Grant Program

The North American Wetland Conservation Act Grant Program (NAWCA) is funded and administered by the U.S. Department of Interior. This program provides support for projects that involve long-term conservation of wetland ecosystems and their inhabitants including waterfowl, migratory birds, fish, and other wildlife. The match for this program is on a 1:1 basis.

National Fish and Wildlife Foundation (NFWF)

The National Fish and Wildlife Foundation is administered by the U.S. Department of the Interior. The program promotes healthy fish and wildlife populations and supports efforts to invest in conservation and sustainable use of natural resources. The NFWF targets six priority areas which are wetland conservation, conservation education, fisheries, neotropical migratory bird conservation, conservation policy, and wildlife and habitat. The program requires a minimum of a 1:1 match. More information can be found at http://www.nfwf.org/about.htm.

Bring Back the Natives Grant Program

Bring Back the Natives Grant Program (BBNG) is a NFWF program that provides funds to restore damaged or degraded riverine habitats and the associated native aquatic species. Generally, BBNP supports on the ground habitat restoration projects that benefit native aquatic species within their historic range. Funding is jointly provided by a variety of federal organizations including the U.S. Fish and Wildlife Service, Bureau of Land Management, and U.S. Department of Agriculture and the National Fish and Wildlife Foundation. Typical projects include those that revise land management practices to remove the cause of habitat degradation, provide multiple specie benefit, include multiple project partners, and are innovative solutions that assist in the development of new technology. A 1:1 match is required; however, a 2:1 match is preferred. More information can be obtained from http://www.nfwf.org.

Native Plant Conservation Initiative

The Native Plant Conservation Initiative (NPCI) supplies funding for projects that protect, enhance, or restore native plant communities on public or private land. This NFWF program typically funds projects that protect and restore of natural resources, inform and educate the surrounding community, and assess current resources. The program provides nearly $450,000 in funding opportunities annually awarding grants ranging from $10,000-50,000 each. A 1:1 match is required for this grant. More information can be found at http://www.nfwf.org/programs/grant_apply.htm.

Freshwater Mussel Fund

The National Fish and Wildlife Foundation and the U.S. Fish and Wildlife Service fund the Freshwater Mussel Fund which provides funds to protect and enhance freshwater mussel resources. The program provides $100,000 in funding to approximately 5-10 applicants annually. More information can be found at http://www.nfwf.org/programs/grant_apply.htm.

Non-Profit Conservation Advocacy Group Grants

Various non-profit conservation advocacy groups provide funding for projects and land purchases that involve resource conservation. Ducks Unlimited and Pheasants Forever are two such organizations that dedicate millions of dollars per year to projects that promote and/or create wildlife habitat.

U.S. Environmental Protection Agency Environmental Education Program

The USEPA Environmental Education Program provides funding for state agencies, non-profit groups, schools, and universities to support environmental education programs and projects. The program grants nearly $200,000 for projects throughout Illinois, Indiana, Michigan, Minnesota, Wisconsin, and Ohio. More information is available at http://www.epa.gov/region5/ened/grants.html.

Core 4 Conservation Alliance Grants

Core 4 provides funding for public/private partnerships working toward Better Soil, Cleaner Water, Greater Profits and a Brighter Future. Partnerships must consist of agricultural producers or citizens teaming with government representatives, academic institutions, local associations, or area businesses. CTIC provides grants of up to $2,500 to facilitate organizational or business plan development, assist with listserve or website development, share alliance successes through CTIC publications and other national media outlets, provide Core 4 Conservation promotional materials, and develop speakers list for local and regional use. More information on Core 4 Conservation Alliance grants can be found at http://www.ctic.purdue.edu/CTIC/GrantApplication.pdf.

Indianapolis Power and Light Company (IPALCO) Golden Eagle Environmental Grant

The IPALCO Golden Eagle Grant awards grants of up to $10,000 to projects that seek improve, preserve, and protect the environment and natural resources in the state of Indiana. The award is granted to approximately 10 environmental education or restoration projects each year. Deadline for funding is typically in January. More information is available at http://www.ipalco.com/ABOUTIPALCO/Environment/Golden_Eagle.html

Nina Mason Pulliam Charitable Trust (NMPCT)

The NMPCT awards various dollar amounts to projects that help people in need, protect the environment, and enrich community life. Prioritization is given to projects in the greater Phoenix, AZ and Indianapolis, IN areas, with secondary priority being assigned to projects throughout Arizona and Indiana. The trust awarded nearly $20,000,000 in funds in the year 2000. More information is available at www.nmpct.org